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OF
1981 WESTERN REGION
TECHNICAL SYMPOSIUM

ASSOCIATION
OF
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The 1981 AOC/DoD Western Region Technical Symposium included a broad range of subjects. Senior Officers and Researchers from the US presented overviews, discussions, and technical papers on policy, doctrine, R & D, technology, and operations. Subjects covered included "Command Control-Communications Countermeasures (C3CM)," "Hidden and Jam-Resistant Communications," "Electro-Optics and Millimeter Wave Techniques," and "Electronic Warfare Training."
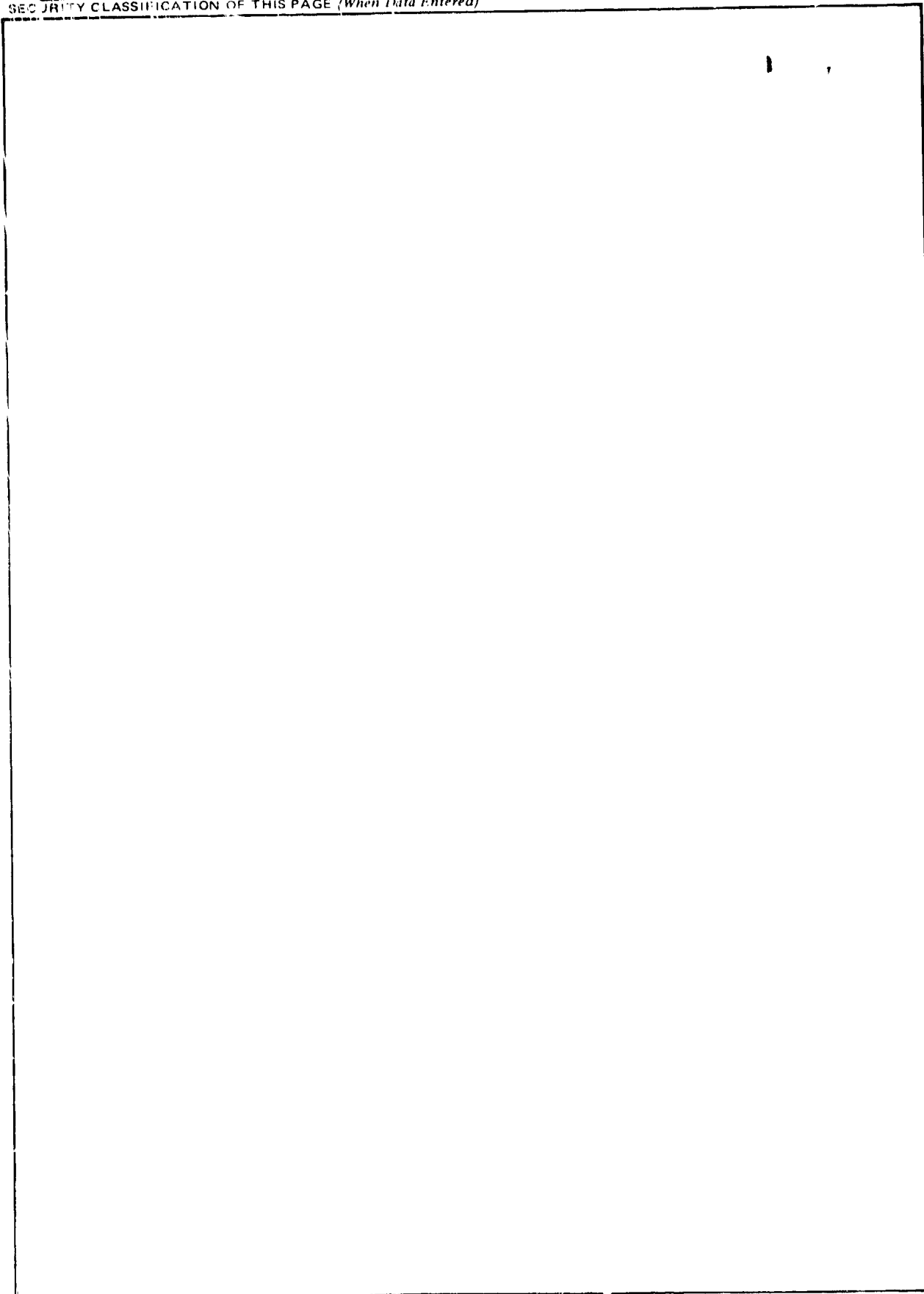
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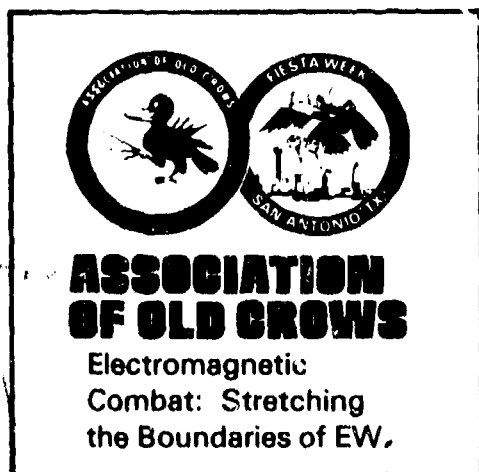
on Electronic Warfare

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Electromagnetic
Combat: Stretching
the Boundaries of EW.

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A MESSAGE FROM THE CHAIRMAN
OF THE
WESTERN REGION EW TECHNICAL SYMPOSIUM

Once again, I am happy to welcome all of you to San Antonio and to the 1981 Western Region Association of Old Crows Electronic Warfare Technical Symposium. With the presence in San Antonio of the Electronic Security Command and the Air Force Electronic Warfare Center, and with the founding here of the Joint Electronic Warfare Center, San Antonio is emerging as one of the country's leading centers of electronic warfare technology. This seems only fitting for a city with such a strong heritage of military activity and tradition. For these reasons, we are very fortunate to be able to present this important symposium here in San Antonio.

Our Technical Program Committee has assembled a splendid technical program, one which is particularly pertinent in view of the current global situation and the long-awaited revitalization of our military forces. We have also organized what we believe is a fine social program and an expanded technical exhibits program. I hope that each of you will be able to participate in all of the events which have been planned.

My heartfelt thanks go out to all of the committee chairmen and their staff members for the long hard hours they devoted to organizing and to implementing this symposium. They are important people, with busy schedules, and devoting time to this symposium involved substantial personal sacrifice on their part. We deeply appreciate the support of our military coordinators, the national AOC officers, and the companies which are participating in our exhibits program.

With the hope that each of you finds our symposium enjoyable and rewarding, I extend to you my warmest personal regards.

RICHARD B. CURTIN
Southwest Research Institute

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SESSION I
"COMMAND CONTROL-COMMUNICATIONS COUNTERMEASURES (C3CM)"

Chairman: Colonel K. A. (Mike) Gilroy, USAF
Commander
Air Force Electronic Warfare Center

"AN OVERVIEW OF THE JOINT ELECTRONIC WARFARE CENTER"

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Washington, DC   20301

This 30 minute SECRET briefing provides a thorough overview of the Joint Electronic Warfare Center. The JEWC opened on 1 October 1980, with an initial cadre of 70 personnel drawn from all four military services as well as civilian employees. The present Director of the Center is Air Force Major General Doyle E. Larson, who is also the Commander of the Air Force Electronic Security Command.

The mission of the Joint Electronic Warfare Center is to provide, upon request, comprehensive analytical support to EW aspects of military operations and EW technical assistance to the Secretary of Defense, the Joint Chiefs of Staff, the Military Services, the unified and specified commands, and other Department of Defense agencies by providing EW combat analysis support to U.S. forces, by conducting assessments of the capabilities and vulnerabilities of U.S. EW/C3CM equipment and employment concepts, by maintaining comprehensive EW data to satisfy EW information requirements, by providing special EW research and study support, and by assisting joint operations planners in EW support.

The four Directorates of the JEWC: Operations, Concepts and Doctrine, Studies and Analysis, and Management Support are described in detail in the briefing. Recent examples are given of the JEWC's involvement in combat EW evaluation, support to joint exercises, the MIJI program, the ASPJ program, TRI-TAC, joint C3CM concepts, the RDJTF, Red, Blue, and Gray data base development, and computer modelling.

C3CM: PUTTING IT ALL TOGETHER IN TEAM SPIRIT 80

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San Antonio, Texas 78243

SUMMARY/ABSTRACT

The elements of Command, Control, and Communications Countermeasures (C3CM) were exercised together for the first time in a 1980 Joint Chiefs of Staff-sponsored exercise in the Republic of Korea called TEAM SPIRIT 80. Offensive and defensive aspects of C3CM were employed in the form of exploitation, deception, communications jamming, electronic countermeasures (ECM) and simulated destruction. The use of operations and communications security (OPSEC/COMSEC) were used to improve the integrity of communications.

C3CM planners identified C3 targets; deconflicted radio, radar, and jammer frequencies; developed an aggressive deception and jamming program; and localized critical communications nodes for the COMSEC elements to monitor. These plans were executed daily in scenarios involving Close Air Support, Air Support Radar Team, and Interdiction missions, and against an array of communications networks including inter-base radios and surface-to-air missile communications nets. Two composite strike exercises, the main thrusts of C3CM interplay, pitted "enemy" forces against "friendly" forces.

All C3CM information was funneled in near real time to a C3CM cell where team members jointly discussed the dynamic battle situation and advised the C3CM Director of the options available to him. The C3CM Director had the final decision authority to use non-lethal assets to jam, deceive, or exploit C3 targets, or to designate them for destruction.

TEAM SPIRIT 80 proved the synergistic effect of integrating the four C3CM elements in a central decision and control facility, and identified shortcomings in some C3CM resources. The exercise also helped to validate a new C3CM Concept of Operations for the Pacific Air Forces.

C^3CM - IS THE RECIPE CORRECT?

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ABSTRACT

The commander of tactical forces in modern combat must have the benefit of C^3CM. To wield this vital weapon, however, he must have an effective C^3CM capability. The missing ingredient, the "I", is Tactical Information, the real time basis for effective countermeasures. To complete the recipe for effective C^3CM will require rapid vigor - our joint-service action.

SUMMARY

The effectiveness of the tactical commander in modern combat depends in the ultimate sense on his command control communications (C^3). There is no alternative to engaging in electromagnetic combat. In modern warfare the tactical commander enjoys the advantage if he can win consistently in the arena of electromagnetic combat: skillfully attacking and degrading the opponent's C^3 while ensuring the effectiveness of his own.

This paper examines current C^3CM concepts and the mix of capabilities required for implementation. Two factors become clear at the outset of our assessment. First, C^3CM is best examined as a joint-service problem. This becomes clear when we consider possible scenarios for future conflict. With a few isolated exceptions, joint combat operations will prevail. Our global disposition of forces dictates this aspect.

Secondly, the C^3CM label is like an incomplete recipe: there is a vital ingredient missing! The designation C^3ICM better portrays the requirement. (With the "I" representing intelligence, or more accurately, tactical information.) The authors have previously examined the commonality of the information needs of all tactical commanders, regardless of component or size of command. The driving force behind our counter C^3 efforts must be that of neutralizing or destroying the enemy's ability to direct and coordinate his forces; but, the fundamental ingredient in our recipe for achieving this dominance is timely and accurate information from which we can project our countermeasures. At higher levels, utilizing "finished" intelligence, C^3CM efforts can be organized and directed, but it is the forward edge of the battle area that the effect is most telling. If the information obtained translates to the raw coordinates of an enemy command post, then the most effective countermeasure, destruction, can be undertaken.

It is our belief that the most effective C^3CM are those measures taken at the lowest practicable level of command, based on real time information. This is, however, much more easily said than done. We, the U. S. forces, simply don't have the necessary capability to do the job.

It's not just that there are far fewer jamming assets than are needed. The real missing ingredient in our C^3CM recipe is the lack of information collection, processing, and particularly, analysis capability available to the front line commander. The Defense Science Board Summer Study of 1976, for example, pointed out the skills required to accomplish effective deception, one of the stated C^3CM options. The personnel skills and background requirements listed for that single option would make it difficult to adequately man a theater level capability, let along the levels where it could be applied most effectively. The linguistic skills alone limit our capacity in this area and given the Soviet integration of "Maskirovka" doctrine into their operations planning we may find ourselves hard pressed to identify and locate the most lucrative C^3CM targets in time to take effective C^3CM action, even where the capability exists.

We suggest a comprehensive rethinking

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of our C^3CM concepts and goals emphasizing simplicity of concept, doctrine, implementation and professional preparation. Given the realities of defense budget limitations and system lead time, the best approach appears to be joint service integration of effort to build a professional, joint tactical C^3CM capability as a recognized battlefield function integrating all existing tactical information and countermeasures assets responsive to the needs of the tactical commander.

C3CM: THE BOYD CYCLE'S THROTTLE

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As government, industry, and society in general continue to grow in size and complexity, the need for new, more effective procedures and techniques to understand and resolve the inherent problems of using untried technology becomes more acute. Modeling has emerged as the technique which is superior to all others in regards to comprehending the mechanisms of large and/or complex systems. Modeling is usually divided into two broad categories, static and dynamic, and can be used at different levels of inspection as:

(1) an explanatory device to define a system or problem;

(2) an analysis vehicle to determine critical elements, components, and issues;

(3) an assesor to formulate and evaluate proposed solutions;

(4) a predictor to forecast and aid in planning future development.

Simulation, as a rule, uses dynamic models to determine what effect proposed inputs have on a system's output. On the other hand, static models generally deal with defining what a system is and understanding how it works. A static model can be (1) iconic (scaled), (2) mathematical, or (3) graphical.

Just as civilian systems throughout the world have grown in complexity, mi .tary systems also continue to be elevated to ever higher levels by the use of increasingly sophisticated technology for armed conflict. As new capabilities are introduced onto the battlefield, measures to counter such momentary advantages are never far behind.

The key to designing an effective countermeasure is understanding the threat against which it must operate. Not surprisingly, modeling has been used extensively to analyze hostile threats. A model exists which concisely portrays the function of command, control and communications during conflict. In 1979, Colonel John Boyd, USAF (Ret) presented his "asymmetric fast transient" theory of conflict to the Air Command and Staff College, Air University. The Boyd cycle describes conflict by defining four abstract, sequential phases of engagement labeled observation, orientation, decision, and action. Those four phases are repeated cyclically by all opponents during an engagement until an advantage is gained.

Boyd postulated that a temporary advantage could be gained by manipulating your opponent's cycle or your own so that a positive, cycle speed difference was generated. If such an advantage was maintained through enough cycles, an opportunity for victory would arise. Such an opportunity would come from application of one of the principles of war.

Total cycle time is determined by summing the individual phase times and the time consumed by all links between the phases. Therefore, a cycle is directly dependent on the processing time associated with each phase and is also directly dependent on the time used by the connecting links. Stretch out a phase or a link, slow down the cycle. Speed up a phase or a link, compress the cycle. The connecting links between two phases are, of course, command and control communications.

SESSION II
"HIDDEN AND JAM-RESISTANT
COMMUNICATIONS"

Chairman: Brigadier Gen ral Melbourne Kimsey, USAF
Director for Tactical Systems
National Security Agency

HIDDEN AND JAM RESISTANT COMMUNICATIONS - ARMY

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ABSTRACT

This paper will provide an overview of the U.S. Army present capabilities in the area of hidden and jam resistant communications. In the introduction, some definitions of the terms hidden and jam resistance will be provided to set the stage for present and future Army concepts and capabilities. The term hidden may take on many ramifications and the paper will highlight the variations of the term itself as it relates to Army communications capabilities. Jam resistance has a more exact definition as it relates to Army operations in the field and it also denotes and defines a series of hardware approaches which will also be discussed.

Next the paper will discuss the management of communications systems on the battlefield to optimize their resistance to enemy intentional communications denial tactics. The paper will finally describe anticipated problem areas that need to be resolved, not only in the management of communications, but in the hardware to be developed by the Army.

SUMMARY

The US Army recognizes its requirements to provide security both of a physical and electrical nature for its communications means on the battlefield.

This presentation has outliend current Army programs and operational concepts that are amenable to capitalizing on both signals management and hardware concepts that would minimize the susceptibility of Army communications support for the future battlefields, the most significant of which is the management of spectrum utilization. Proper spectrum utilization is the key for an efficient use of electronic communications means on the battlefield.

The Army has just undertaken a detailed study of its spectrum management requirements and is proposing a series of automated assists for coordinating and managing its use of frequency related systems.

Jamming is well recognized as a significant deterrant to effective communications. The Army has a series of hardware developments, some relating to antenna systems and others to the basic radio equipment itself to minimize enemy ECM activities. Among these developments are antenna systems which provide a capability to minimize pattern radiation in undesirable directions. Others relate to specific schemes for minimizing enemy intercept of information, all of which will contribute to the minimizing of enemy successes in the field of electronic countermeasures.

But a most significant factor will be the operators of these systems. Their proper training will be essential for continued success in this arena.

RADIOELECTRONIC COMBAT

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ABSTRACT

Radioelectronic Combat (REC). To support Soviet emphasis on effective use of the electromagnetic spectrum in all aspects of what we call electronic warfare (EW), they have developed a military concept called RADIOELEKTRONNAYA BOR' BA, which we translate as "Radioelectronic Combat (REC)."

REC has been defined as the total integration of electronic warfare and physical destruction resources to deny an enemy use of his electronic control systems and to protect friendly electronic control systems from disruption by the enemy.

REC adds a new dimension to EW with the inclusion of reconnaissance data and firepower for the destruction of electronics. EW has traditionally been viewed as an attempt to exploit or deny the enemy use of the electromagnetic spectrum - in the classical sense, EW seeks to attain a technical objective somewhat in isolation from friendly battlefield objectives. Soviet REC, however, has the objective of disruption of enemy control and is a military objective in itself. REC may be considered a misnomer for what could be called Control Warfare, where the objective is to disrupt enemy control while protecting friendly control.

This paper briefly details, at the SECRET/ NOFORN level, the current Soviet doctrine, organizational structure, and supporting equipment developed to meet these electromagnetic combat objectives.

AN OVERVIEW OF
TACTICAL AIR-TO-GROUND JAM-RESISTANT COMMUNICATIONS PROGRAMS

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ABSTRACT

Briefing presents an overview of USAF tactical air-to-ground jam-resistant communications programs currently in development and acquisition. Programs discussed are HAVE QUICK, SEEK TALK, SINCGARS, and JTIDS. Details are provided on program objectives, applications, status, and schedules.

SUMMARY

Increased emphasis has been placed in recent years on the vulnerability of our communications systems to enemy electromagnetic countermeasures (ECM). Due to this emphasis, the role of electromagnetic counter-countermeasures (ECCM) in the design and operation of communications systems has also taken on increased importance. There are currently numerous programs in the various stages of development and acquisition whose goal is to decrease our ECM vulnerabilities by increasing the jam-resistance of our communications systems. These programs span the range of communications systems, from air-to-ground radios and tactical ground radios to satellite communications. The purpose of this briefing is to provide an overview of the major USAF anti-jam programs which deal with tactical air-to-ground communications, since this is an area in which a great amount of effort is currently being expended. Since the briefing presents an overview of major USAF programs, it will not go into great detail on individual programs nor will it detail the threat which each system is being designed to defeat.

The first program discussed is HAVE QUICK. HAVE QUICK is a near-term program which is designed to provide an interim anti-jam capability for selected tactical aircraft and ground command and control sites. This program uses existing technology to provide a quick ECCM fix in the UHF frequency band. Installation of the HAVE QUICK modification to existing radios began in January, 1981. The long-term fix in the UHF air-to-ground band is the SEEK TALK program which is currently in the development phase. SEEK TALK will be installed on practically all USAF tactical aircraft and associated ground command and control sites, beginning in the mid 1980's. Jam resistance in the VHF band is currently being pursued by USAF participation in the Army SINCGARS program. Installation of a SINCGARS compatible capability in selected USAF aircraft will allow anti-jam interoperability with similarly-equipped Army units. Current SINCGARS schedules call for the VHF anti-jam capability to be available in the late 1980's.

The final program discussed is JTIDS. JTIDS Class I terminals provide an air-to-air and air-to-ground anti-jam data link between the Airborne Warning and Control System E-3A aircraft and ground command and control sites. These terminals are currently being procured. The JTIDS Class II terminals are designed for installation in selected tactical aircraft and will provide for an anti-jam data link between the individual aircraft as well as between the aircraft and the E-3A and ground command and control sites. The Class II terminals are currently being developed and are scheduled to be available for installation in the late 1980's.

SATELLITE ELECTROMAGNETIC VULNERABILITY ANALYSIS

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ABSTRACT

Communications by satellite are destined to play an increasingly important role in modern warfare. Unfortunately, space communications systems are susceptible to both lethal and non-lethal threats. This paper examines satellite vulnerability, with heavy emphasis on electromagnetic vulnerability. The extent of the threat is examined and techniques for countering that threat are detailed.

SUMMARY

No one any longer questions the supreme importance of reliable communications to the successful conduct of modern warfare. Since communications by satellite provides many advantages, especially for military applications, the importance of MILSATCOM systems will inexorably increase. This paper examines the current vulnerability of our MILSATCOM systems and looks at potential solutions to enhance their electromagnetic invulnerability.

A satellite communications system consists of a constellation of satellites, a set of earth (ground, sea, and air) terminals, and the associated procedures governing the employment of that system. The vulnerability of such a system refers to its characteristics which cause it to suffer a definite degradation (incapability to perform the designed mission) as a result of having been subjected to a certain level of effects in an unnatural (man-made) hostile environment.

Of course, both earth and space terminals are vulnerable. Ground terminals are vulnerable to all destruction means appropriate to their carrier (airborne, seaborne, ground mobile, fixed), from terrorist activity to anti-radiation missiles to nuclear weapons.

For reasons developed in the paper, concentration is on the vulnerability of the space segment of MILSATCOM systems. Satellites are at one and the same time inherently invulnerable and vulnerable: invulnerable because they are far away and vulnerable because they are locatable, relatively soft and defenseless, and accessible, although with some difficulty. Threats to communications satellites may be generally characterized as physical or electromagnetic. The paper gives several details of the physical threat, including directed energy weapons, electromagnetic pulses, and convention ASATs.

Flexibility of employment and covertness are good reasons to choose electromagnetic over physical destruction as a means of negating satellite effectiveness. Electromagnetic negation of a MILSATCOM system may be attempted through exploitation, deception, or jamming. Exploitation refers simply to the intercept and use of signals. Satellite links, both uplinks and downlinks, may be intercepted. Uplinks may be intercepted and recorded for later analysis by satellites within line of sight of the transmitter (not a severe restriction) or by aircraft or ships in the reflected or refracted path of the signal. It is absolutely clear that all communications via satellite are totally vulnerable to being intercepted and exploited. This is true of both secure (encrypted) and unsecure links; however, secure links afford a high degree of protection from useful exploitation even if they are intercepted. The actual protection is a function of many variables and involves information classified beyond the classification of this paper; hence, no further discussion of secure communications is included. (Clearly, even secure communications can be jammed. Indeed, it is probable that secure links are more vulnerable to jamming than non-secure links, since the encryption "black box" provides an additional point of jamming vulnerability.)

Deception might be an effective way to defeat MILSATCOM missions. Deception refers to the intentional introduction of radiation into the satellite link in an attempt to imitate the intended signal. Such deceptive signals could cause false control commands. The paper provides several details of the threat and uses past analyses as examples of existing system vulnerabilities.

It is important to realize at the outset of this discussion that there are no 100% solutions. This should be no shock: no other military system can be made invulnerable - neither can MILSATCOM systems. And like other systems, the correct approach to limiting our vulnerability should include multiple techniques.

We cannot effectively prevent our satellite links from being intercepted; it is just too easy to receive satellite downlinks. We must therefore exercise extreme care in what we transmit over unsecure links; we must protect more sensitive information by encryption.

No electromagnetic transmission can be made totally invulnerable to jamming. In the jamming game, the jammer seeks to deny his enemy's communication while the communicator seeks to make it as costly as possible for the jammer to succeed. The communicator's basic principles are almost axiomatic: force the jammer to spread his available energy over a wide range of frequency, time, and space.

Frequency diversity, more commonly called "spread spectrum," is achieved by one of two techniques: direct spreading or frequency hopping. Basically, a receiver is prevented from understanding its message when the ratio of undesirable energy is "too high". That "too high" threshold is a function of several complex parameters such as receiver sensitivity. demodulation processing, etc. Implied in the undesirable/desirable energy ratio is a given frequency bandwidth and time slot. The spread spectrum technique known as direct spreading spreads the desired message or information over a frequency bandwidth much larger than required to support the information. The spread spectrum technique of frequency hopping is similar in principle, simpler in concept, but more complicated in implementation. The message or information is transmitted in its required bandwidth, but it is transmitted at a frequency which changes with time. Time diversity is almost self-explanatory. It differs from frequency hopping in that it transmits over a fixed frequency channel but in short bursts unknown to the jammer.

Space diversity refers in this paper to ability of an antenna to control the direction of the maximum radiated and received electromagnetic energy. Control of the direction of received energy does the same thing in reverse. In addition, with control permitting an antenna null, a space terminal could be able to selectively determine a jammer location and "decide" not to receive that jamming energy by placing an antenna null in that direction. Multiple nulls will be possible. Antenna nulling is expected to be implemented on DSCS III, and it seems to be an increasingly important technique. Combinations of these techniques can produce hybrid jam resistant systems with reliable communications capability even in the presence of a jammer whose power is hundreds of times that of the friendly transmitter.

An important part of the overall solution, then, is the consideration of and tradeoff among the possible solutions in light of the known and projected threat. This tradeoff process implies a considerable analysis capability if we are to adequately model and quantitatively consider alternatives in order to achieve the best compromise for new MILSATCOM systems. AFEWC is developing a generic analysis methodology for the detailed analysis of satellite electromagnetic links. This analysis tool will be applicable to all satellite electromagnetic links, not just to communications satellites. It will model the solutions discussed above and will thus be useful in performing design tradeoffs. The sensitivity of effective communications to various design options, threats, and operational scenarios will be determinable.

The conclusion is clear. The development of electromagnetically secure MILSATCOM systems is made imperative by the confluence of four factors: the essential and central role of communications, command, and control in warfare; the increasing importance of MILSATCOM systems (it is the only solution for certain requirements); the electromagnetic vulnerability of satellite links; and the suspected enemy doctrine of defeating communications, command and control systems. While the absolute protection of MILSATCOM systems is out of the question, many partial solutions exist. These partial solutions, when collectively applied and implemented, can provide more than an adequate level of protection. What is an "acceptable level of protection"? How do we develop and implement this protection? These are the central questions. Given the absolute necessity of an acceptable solution and the high cost of that solution (several billions of dollars over the next 10-15 years), it is imperative that DoD decision makers understand the tradeoffs associated with the various alternatives. This understanding is possible only through a well orchestrated program of technology development, system designs satisfying user requirements, and intelligence collection. The analysis and interpretation of these simultaneous factors is a difficult and challenging task involving many players. This analysis must present understandable and meaningful choices to decision makers. Those decisions will play a significant role in the security of this country.

LOW COST ANTI-JAM DATA LINK

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ABSTRACT

Low Cost Anti-jam Data Link (LCAJDL) is a multifunction data link system under study at Hughes with RADC sponsorship which provides both single point guidance for multiple simultaneous smart bomb/guided missile delivery and multi-rate voice/data communications relay between ground based command centers: The multi-terminal network uses a spread spectrum waveform integrated with spatial processing to provide anti-jam (AJ) and low probability intercept (LPI) protection.

SUMMARY

The Low Cost Anti-jam Data Link study will develop systems concepts for a multifunction/multi-rate Ku-band anti-jam data link to provide linking of ground based command and control elements through an airborne relay and guidance links for multiple smart bomb/guided missile delivery. The design approach will achieve cost reductions by concentrating the network complexity in the airborne relay platform and minimizing the complexity of the remote members of the network. The emphasis will be on utilizing newly developed temporal and spatial AJ/LPI technologies. Special attention will be given to the development of a robust system design capable of operation in a complex EW environment. The preliminary design calls for a 20 MHz direct sequence spread spectrum TDMA waveform to service both communications and weapon guidance functions. Frequency hopping and adaptive null steering antennas will be modular additions to he basic system for higher threat missions.

The TDMA waveform will provide the capability to adaptively assign increased AJ assets to a terminal operating in a high jamming en-

vironment. The master terminal can assign multiple time slots to any remote terminal to allow lower data rates and increased processing gain.

For the weapons delivery mission, the airborne master terminal will use PN tracking to provide high accuracy range measurements. The phased array with precision monopulse angle measurement provides weapon location accuracy consistent with operational requirements and provides the capability for servicing up to 20 weapons in the enroute and terminal phases. The array design utilizes a multiloop coherent sidelobe canceller to null multiple broadcast jammers which are attempting to disrupt either the communications or the angular position measurement functions of the relay.

The anti-jam performance of the basic LCAJDL system is variable and depends on the selected data rate and the length of the time slot assigned to the transmission. The 20 MHz PN provides up to 30 dB processing gain for a 10 bit message in a 4 millisecond time slot. Error correcting codes and interleaving for pulsed jamming protection are included in the design under study. Fast frequency hopping is being evaluated as modular add-on for high threat missions.

The LPI performance of the LCAJDL is being evaluated against the radiometer threat operating at highly negative signal to noise ratios. Preliminary analyses show that the master terminal transmissions cannot be intercepted across the FEBA. The probability of intercept of weapon terminals and ground based command control centers is under evaluation.

The objective of this paper is to outline the required capabilities, system design problems and the technology capabilities/limitations in meeting these system requirements.

MANY-ON-MANY COMJAM MODEL

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I. SUMMARY

As late as 1977 Jamming analysis was performed using the highly simplistic one-on-one free space loss model as discussed in a 1947 Bell Labs report. That model evolved into a simplistic free space loss one-on-many model, which in turn evolved into a fairly complex one-on-many model which computed atmospheric propagation attenuation as a function of altitude, polarization, type terrain, frequency and range. The next logical evolutionary step was to develope the algorithms necessary to evaluate the interaction of many jammers against many transmitter sites. The Vulnerability and Analysis Branch of the AFEWC has developed a communications jamming (COMJAM) model for use on a desk-top microcomputer that incorporates multiple jammers directed against multiple transmitting sites. This desk-top microcomputer is a Textronix 4052 with 64k internal core storage. This COMJAM Model allows the user to create numerous scenarios. Multiple jammers, ground or airborne, against multiple receiving sites, ground or airborne, are examples. The model incorporates the following system parameters: latitude/longitude, attitude, power, antenna gain, bandwidth, frequency, antenna polarization, terrain type, receiver gain, maximum communicating distance, and lastly, required J/S ratio for communications. Three types of outputs (2 graphic, 1 numeric) can be obtained, depending on the application. The first is a J/S contour line around a transmitting site, where the contour represents the distance out to the required J/S for reception by a receiver. If a receiver is located within this closed contour, than communications can occur. The second output, a link analysis is a simplified version of the first. Here solid, dashed, or no line is drawn between the transmitting sites. A solid line represents two-way communications, a dashed line represents one-way communications, and no line represents total disrupted communications. This form of output constitutes a rapid "First Look" COMJAM effectiveness evaluation, and forms the basis for further model and network in-depth evaluation. The third output is a numerical listing of data in tabular form. In keeping with current consumer needs, this many-on-many COMJAM Model will enable analysts to upgrade the quality and accuracy of a given COMJAM effectiveness evaluation, using a desk-top computer. This M-O-M Model is a step towards a total network vulnerability analysis.

II. TERMINOLOGY

As much as possible, terminology used represents standard symbols used in the EW community. Figures 1 and 2 gives the geometric relationships for a one-on-one and many-on-many analysis.
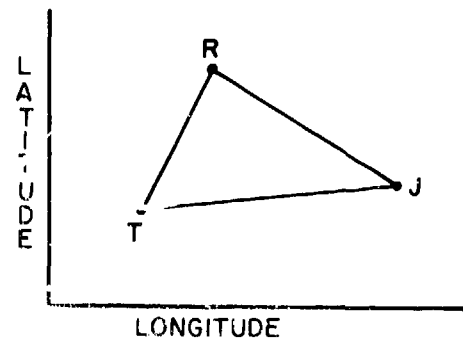
WHERE   T = TRANSMITTER

            R = RECEIVER

            J = JAMMER

Fig. 1 Geometric relationship between a Jammer, Receiver, and Transmitter (one-on-one)
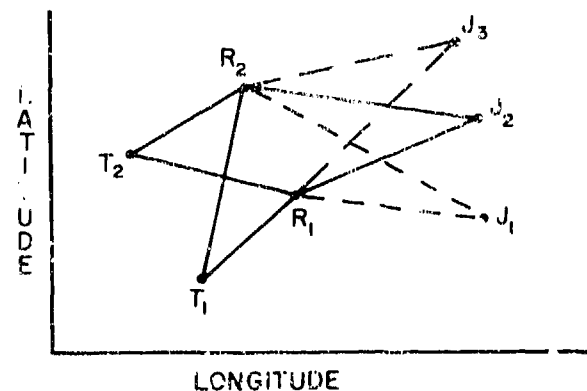

Fig. 2 Geometric relationship between a Jammer, Receiver, and Transmitter (many-on-many)

III. LIMITATIONS

As with all computer simulation models, certain assumptions and limitations must be placed on the model in order to obtain results in a reasonable amount of time. Thus, this COMJAM Model has the following assumptions/limitations:

a. Core Storage. Model will handle seventy locations maximum. For example; twenty jammers against a network of fifty transmitter locations can constitute a scenario. Run time varies according to scenario configuration; however, with four jammers against five transmitting locations the run time was 9.2 minutes and with fourteen jammers against eleven transmitting locations the run time was sixty minutes.

b. Distance Measurements. Accurate distance measurements cannot, at the present time, be taken directly off the graphic output. To date program uses 60NM latitude/longitude square grid. In the future, graph projections such as Mercator and Lambert Conformal with two standard parallels are expected to be incorporated.

c. Jamming Powers Additive Currently, program uses noise jammers operating on a scenario frequency compatible with transmitters and receivers. Thus the fundamental assumption is that the average power from broadband noise jammers are additive in the frequency domain. Other jamming techniques such as Sweep jammers and Pulse jammers are not considered. Also, due to their complexity, phase relationships are not considered.

d. Terrain Data. Terrain data such as mountains are not considered. Program assumes a smooth spherical earth between source and destination.

e. Antennas. All antennas are omni-directional in azimuth with antenna patterns not incorporated.

IV. ELEMENTS OF MODEL

The many-on-many COMJAM Model is composed of four programs and will operate one-on-one, one-on-many, and many-on-many. The first is the controller, called MASTER, which sets up all arrays, constants, and appends from DISC the appropriate programs. Incorporated within the Master program is the input program to enable you to create a data base of jammers and transmitters. Second, is the scenario creation program, called INSELECT, which allows you to create, review, and change scenario data. The COMJAM Model allows the user to create numerous scenarios. Multiple jammers, ground or airborne against multiple receiving locations, ground or airborne, are examples. All variables except jammer and transmitter names can be changed for each proposed scenario with the added option of changing the data base if need arises. The third program, "COMPUTE", actually computes the radial distances out to the required J/S for each ten degrees around each transmitter location. The fourth and last program is the graphics, called GRAPHICS, which is a highly versitile plotting program. Tables 1 and 2 lists the input variables needed for both jammers and transmitter.

Parameter	Units
Name	Equals 9 alphanumeric characters
Designation	Point, Plus, Square, Diamond, Triangle, Fighter, Bomber, Helicopter, GCI-left, GCI-right, GCI-both
Latitude/longitude	±DDD.MMSS Where, N,W are positive
Altitude	Feet
Power	Watts
Antenna Gain	dB
Bandwidth	kHz
Frequency	MHz
Antenna Polarization	Horizontal or Vertical
Terrain type to each transmitter location	Sea Water, Marshy, Average, Plains, Desert

TABLE 1: Jammer Input Parameters

Parameter	Units
Name	Equals 9 alphanumeric Characters
Designation	Point, Plus, Square, Diamond, Triangle, Fighter, Bomber, Helicopter, GCI-left, GCI-right, GCI-both
Latitude/Longitude	±DDD.MMSS Where N,W are are positive
Power	Watts
Antenna Gain	dB
Antenna Height	Feet
Reciever Altitude	Feet
Antenna Polarization	Horizontal or Vertical
Gain of Receiver	dB
Receiver Bandwidth	KHz
Terrain type of transmitter location	Sea Water, Marshy, Average, Plains, Desert
Required J/S ratio for reception	dB
Maximum coverage distance	Km

TABLE 2: Transmitter Input Parameters

V. MODEL EQUATIONS

There are three sections of equations used to calculate the distance out to the required J/S for each transmitter given the effects of one or more jammers. Briefly, each is discussed.

a. Range and Bearing. (Ref 1-4) Using spherical geometry, the range and bearing from transmitter to each jammer is as calculated following the symbology of Figure 3.

Let Rsd be the range from a source to a destination, and let:

R1 = earth radius in kilometers (km)
P1 = Latitude of source
P2 = Latitude of destination
T1 = Longitude of source
T2 = Longitude of destination
East and South Latitudes be negative

Shown are the following relationships:

$$A1 = | T2-T1 | \text{ for } | T2-T1 | < =180^0 \quad (1)$$
$$A1 = 360 - | T2-T1 | \text{ for } | T2-T1 | >180^0 \quad (2)$$
$$B = 90-P1 \quad (3)$$
$$C = 90-P2 \quad (4)$$
$$SinB = Cos P1 \quad (5)$$
$$CosB = Sin P1 \quad (6)$$
$$SinC = Cos P2 \quad (7)$$
$$CosC = Sin P2 \quad (8)$$

Therefore, $A = Cos^{-1}\{Sin(P1)Sin(P2)+Cos(P1)Cos(P2) Cos(A1)\}$ deg $\quad (9)$

or $A = \frac{\pi}{180} Cos^{-1}\{Sin(P1)Sin(P2)+Cos(P1)Cos(P2)Cos(A1)\}$ rad $\quad (10)$

The Range, Rsd, is found to be
$$Rsd = R1 \cdot \frac{\pi}{180} \cdot Cos^{-1}\{Sin(P1)Sin(P2)+Cos(P1)Cos(P2)Cos(A1)\} \quad (11)$$

To find the corresponding bearing, let
$$T = Sin(P1)Sin(P2)+Cos(P1)Cos(P2)Cos(A1) \quad (12)$$

Then, $C1 = Cos^{-1}\{\frac{Sin(P2)-T \cdot Sin(P1)}{Cos(P1) Sin A}\} \quad (13)$

$B1 = Cos^{-1}\{\frac{Sin(P1)-T Sin(P2)}{Cos(P2) Sin A}\} \quad (14)$

Now, let H1 equal true heading from source to destination. If $|T2-T1|<180$ and if T2 < T1 then H1 = C1, otherwise, if T2 > T1 then H1 = 360-C1. On the other hand, if $|T2-T1| > 180$ and if T2 < T1 then H1 = 360-C1, otherwise if T2 > T1 then H1 = C1.
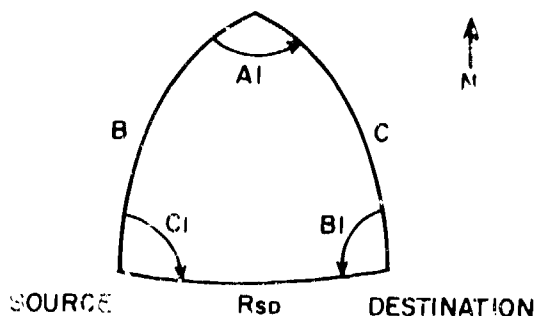

Figure 3: Spherical geometry relationship between source and Destination

If H2 equals the true heading from destination to source (commonly called back bearing), then the following applies. If $|T2-T1| \leq 180$ and if $T2<T1$ then $H2 = 360-B1$, otherwise if $T2 > T1$ then $H2 = B1$. Lastly, if $|T2-T1| > 180$ and also if $T2 < T1$ then $H2 = B1$, otherwise, if $T2 > T1$ then $H2 = 360-B1$.

b. Of primary concern when dealing with communications modeling are propagation losses between source and destination. The propagation model used in this analysis was a modified version of an Emperical Propagation Model (EPM-73) that appeared in IEEE Transactions on Electromagnetic Compatibility (Ref 1). There were two models in the EPM-73. High h/λ ($h =$ height of antenna, $\lambda =$ wave length) Model operated between 40MHz and 10GHz with a maximum antenna height of 3km. Secondly, low H/λ Model operated between 1-1000 MHz with a maximum antenna height of 300m. When h/λ is large, ($h/\lambda > 25$) the high h/λ model is the correct model to use. Similarly, when h/λ is small, ($h/\lambda < .5$) the low h/λ model is appropriate. In the transition region, both models should be used with the largest value taken (Ref 2).

From Tables 1, 2, the input parameters needed for the EPM-73 Model are: frequency, transmitter antenna height, receiving antenna height, distance between transmitter and receiver, vertical or horizontal antenna polarization, and lastly terrain data, of which, sea water, marshy, average, plains, or desert are the possible choices.

c. J/S Calculations. (Ref 3) The COMPUTE program computes the radial distances starting at due north and going clockwise in increments of 10 degrees to the required J/S for reception. This contour envelope, therefore, represents the maximum range that a transmitter can communicate to a given receiver. It should be noted at this time that the contour calculated represents an imaginary path of a receiver and a receiver does not actually exist in the program. The derivation of the calculation will be discussed. First, an assumption is made that the RF emitter, whether jammer or transmitter, is an isotropic (point) source of radiation. The radiation is assumed omnidirectional, that is given off evenly in all directions. Next, the earth is assumed a sphere of radius R. It may also be stated that all radiation from the center of the sphere passes through the surface of the sphere and is evenly distributed over the surface of the sphere. The power Density (Pi) is defined as:

$$Pi = \frac{Ps}{Area} = \frac{Ps}{4\pi R^2} \quad (15)$$

Where: Pi = Power Intensity per unit area (w/km^2)

Ps = Power radiated by source (w)

Area = Area of sphere (km^2)

If the isotropic source is made directional through the use of a directional antenna, the value of Pi increases proportionally to the gain of the antenna in the direction of the antenna. The value of Pi can be represented as:

$$Pi = \frac{Ps}{4\pi R^2} \cdot Gs \quad (16)$$

Where Gs= Gain of source antenna

Now if a receiver is located at a distance R(km) from the isotropic source, and Pi equals the radiation intensity of the wavefront passing the receiver, then the amount of energy extracted from the wavefront is a function of Pi and the receiver antenna's effective cross sectional area, or capture area

$$CS = \frac{Gr}{4\pi} \cdot \lambda^2 \quad (17)$$

Where CS= Cross Section of the antenna (km^2)
Gr = Gain of receiver antenna (dB)
λ = Wavelength of intercepted frequency (km)

Thus, the RF Power entering the receiver (Pr) is:

$$Pr = Pi \cdot CS \quad (18)$$

$$= \frac{Ps \ Gs}{4\pi \ R^2} \cdot \frac{Gr \ \lambda^2}{4\pi} \quad (19)$$

$$= \frac{Ps \ Gs \ Gr \ \lambda^2}{(4\pi R)^2} \quad (20)$$

From Equation 20, the $\lambda^2|(4\pi R^2)$ term is the free space propagation loss which in the COMJAM Model is determined by the EPM-73 Model. To determine the amount of desired signal entering the receiver from a transmitter, called S, we have (Read "→" as becomes):

Pr→S = Signal Power received (w)
Ps→Px = Transmitter Power (w)
Gs→Gx = Transmitter Antenna Gain (dB)
Gr→Grs = Receiver Antenna Gain in direction of transmitter (dB)
R→Rxr = Range from Transmitter to Receiver(km)

Then, Equation 20 can be rewritten as:

$$S = Px \ Gx \ Grx \cdot \left(\frac{\lambda}{4\pi Rxr}\right)^2 \quad (21)$$

Now, to determine the amount of power entering the receiver from a jammer, called J, the symbols become:

Pr→J = Jammer power received (w)
Ps→Pj = Jammer power (w)

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Gs‣Gj = Jammer antenna gain (dB)

Gr‣Grj = Receive antenna gain in direction of jammer (dB)

R‣Rjr = Range from jammer to receiver (km)

Now, Equation 20 becomes:

$$J = Pj\ Gj\ Grj\ \left(\frac{\lambda}{4\pi Rjr}\right)^2 \qquad (22)$$

Finally, dividing Equation 21 by 22, the J/S ratio becomes:

$$\frac{J}{S} = \frac{Pj\ Gj\ Grj}{Px\ Gx\ Grx} \cdot \left(\frac{Rxr}{Rjr}\right)^2 \qquad (23)$$

Where $\frac{Rxr}{Rjr}$ is commonly called the range ratio.

Equation 23 is the fundamental equation used in the many-on-many COMJAM Model.

VI. MODEL OUTPUTS

There are three types of outputs that can be obtained from the many-on-many COMJAM Model. Figures 4, 5, 6 represent the numerical data output consisting of Jammer, Site, and Range

radii for each 30^0 around a transmitter location. Note: These tables are representative samples of jammer and site data. Notice that Jammer four, and Sites four and five are not listed. They are the same types of data shown in figures 4 and 5. Figure 7 is the graphic output showing the envelopes to the required J/S. Remember this envelope represents whom the site can communicate with. If a receiver lies outside the envelope then communications cannot occur. The last output that can be seen is a link analysis as shown in Figure 8. By comparing Figures 7 and 8, the following is deduced: Sites two and four envelopes encompasses site five, but site five's envelope does not encompass site four, therefore, one-way communications in the direction of site five is deduced as shown in the graph.

By continually performing the above, a link analysis is achieved. Lastly, partial overlays are possible. For example, say you are only interested in the envelope around site three. By specifing a partial analysis, Figure 9 is obtained showing the envelope around site three, but still illustrating where the jammers and other sites are located.

THIS IS JAMR DATA TABLE			
JAMR	1	2	3
JAMR NAME	JAMMING01	JAMMING02	JAMMING03
LAT (DDD.dddd)	51.0000	49.9000	48.0000
LONG (DDD.dddd)	-5.2000	-5.1000	-6.0000
JAMR POWER	500	500	500
ANT GAIN (dBI)	6	6	6
JAMR ALTITUDE (FT)	30	30	30
ANT POLARIZATION	VERTICAL	VERTICAL	VERTICAL
BANDWIDTH (KHz)	30	30	30
JAMR FREQUENCY (MHz)	125	125	125
GRD TRAIN TO SITE 1	AVERAGE	AVERAGE	AVERAGE
GRD TRAIN TO SITE 2	AVERAGE	AVERAGE	AVERAGE
GRD TRAIN TO SITE 3	AVERAGE	AVERAGE	AVERAGE
GRD TRAIN TO SITE 4	AVERAGE	AVERAGE	AVERAGE
GRD TRAIN TO SITE 5	AVERAGE	AVERAGE	AVERAGE

Figure 4: Jammer Data Table

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THIS IS SITE DATA TABLE			
SITE	1	2	3
SITE NAME	TRANSMIT 1	TRANSMIT 2	TRANSMIT 3
LAT (DDD.dddd)	48.5090	49.0000	49.2000
LONG(DDD.dddd)	-7.1000	-6.9000	6.3000
XMIT POWER (W)	250	250	250
ANT GAIN (dBI)	6	6	6
ANT HEIGHT (FT)	33	33	33
ANT POLARIZATION	VERTICAL	VERTICAL	VERTICAL
RECVR HEIGHT (FT)	6000	6000	6000
BANDWIDTH(KHz)	30	30	30
GROUND TERRAIN	AVERAGE	AVERAGE	AVERAGE
RECVR GAIN(dBi)	3	3	3
REO J/S RATIO (dB)	-3	-3	-3
RCVR GAIN TO JAM(dB)	0	0	0
MAX COVERACE DIST(Km)	300	300	300

Figure 5: Site Data Table

THIS IS RANGE RADII(KM) DATA TABLE					
DEG	1.0	2.0	3.0	4.0	5.0
30	206.8	179.5	115.1	228.9	288.6
60	270.9	269.3	245.4	279.5	295.3
90	277.9	274.4	262.7	280.9	292.7
120	273.3	259.7	158.5	270.3	280.9
150	132.3	110.8	91.1	167.8	243.1
180	67.0	74.4	72.8	116.2	163.0
210	51.2	66.6	61.8	97.0	112.6
240	50.2	69.0	55.6	74.3	91.3
270	61.2	70.0	47.1	66.7	79.3
300	77.2	68.3	42.3	73.2	82.2
330	91.2	75.9	47.2	83.0	111.2
360	120.9	106.9	67.9	111.2	239.8

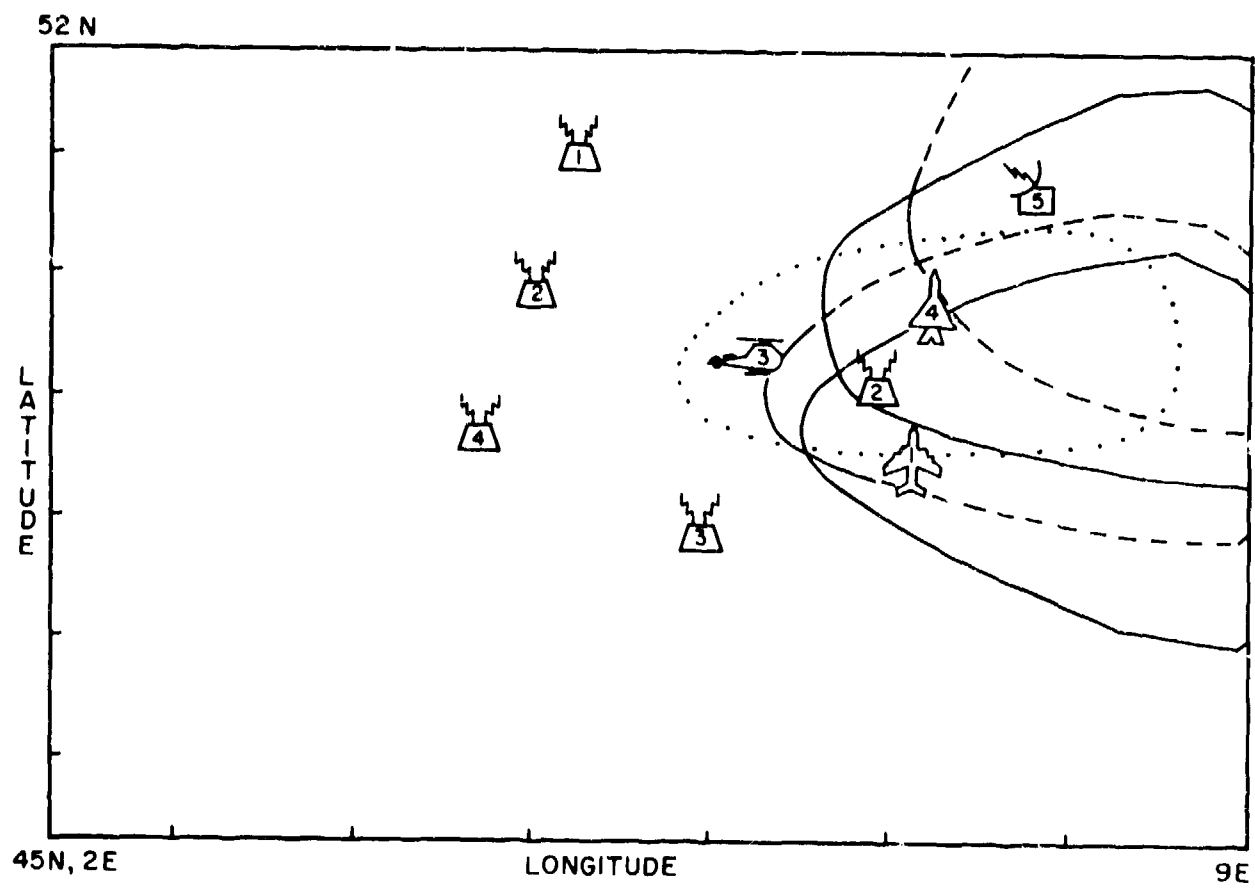Figure 6: Range Radii Data Table

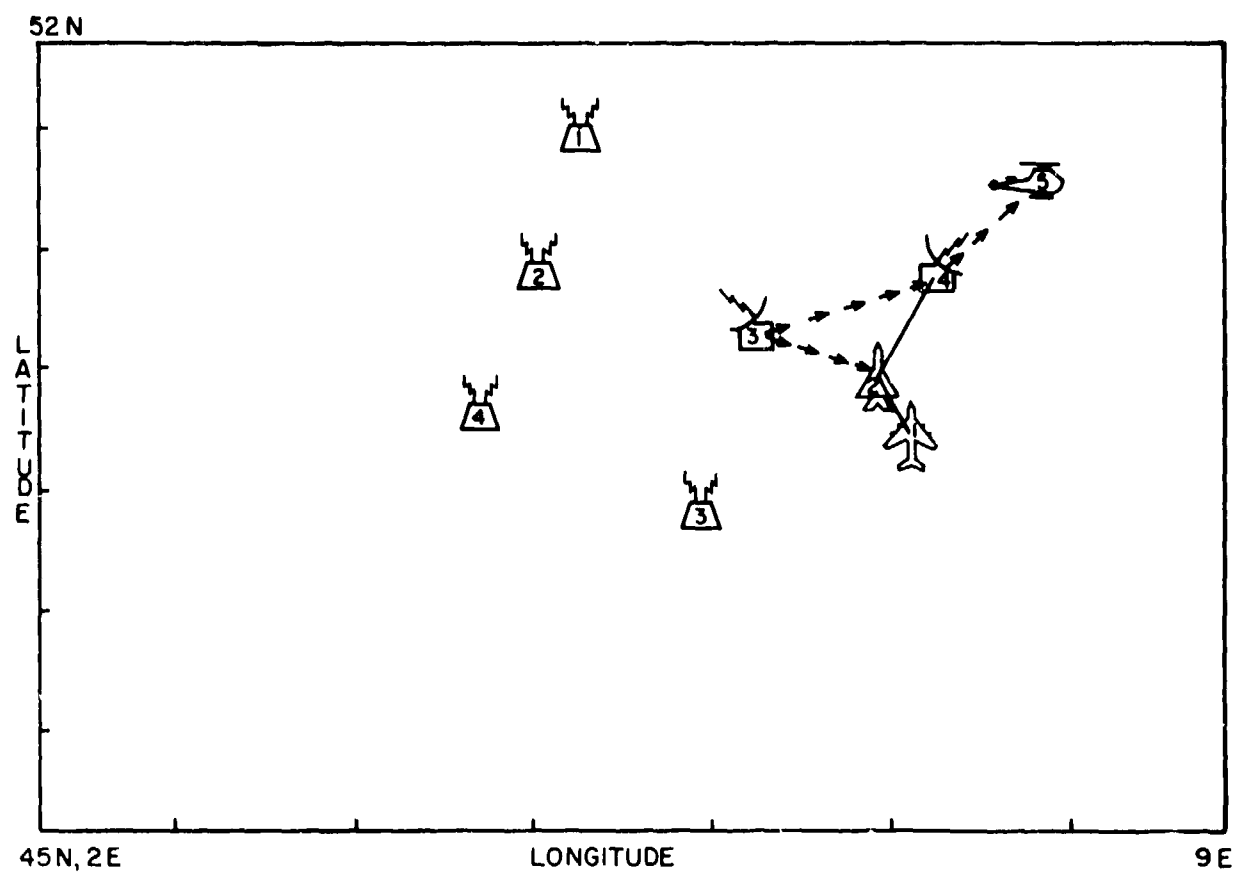24

Figure 7: Graphic Output (not centered)
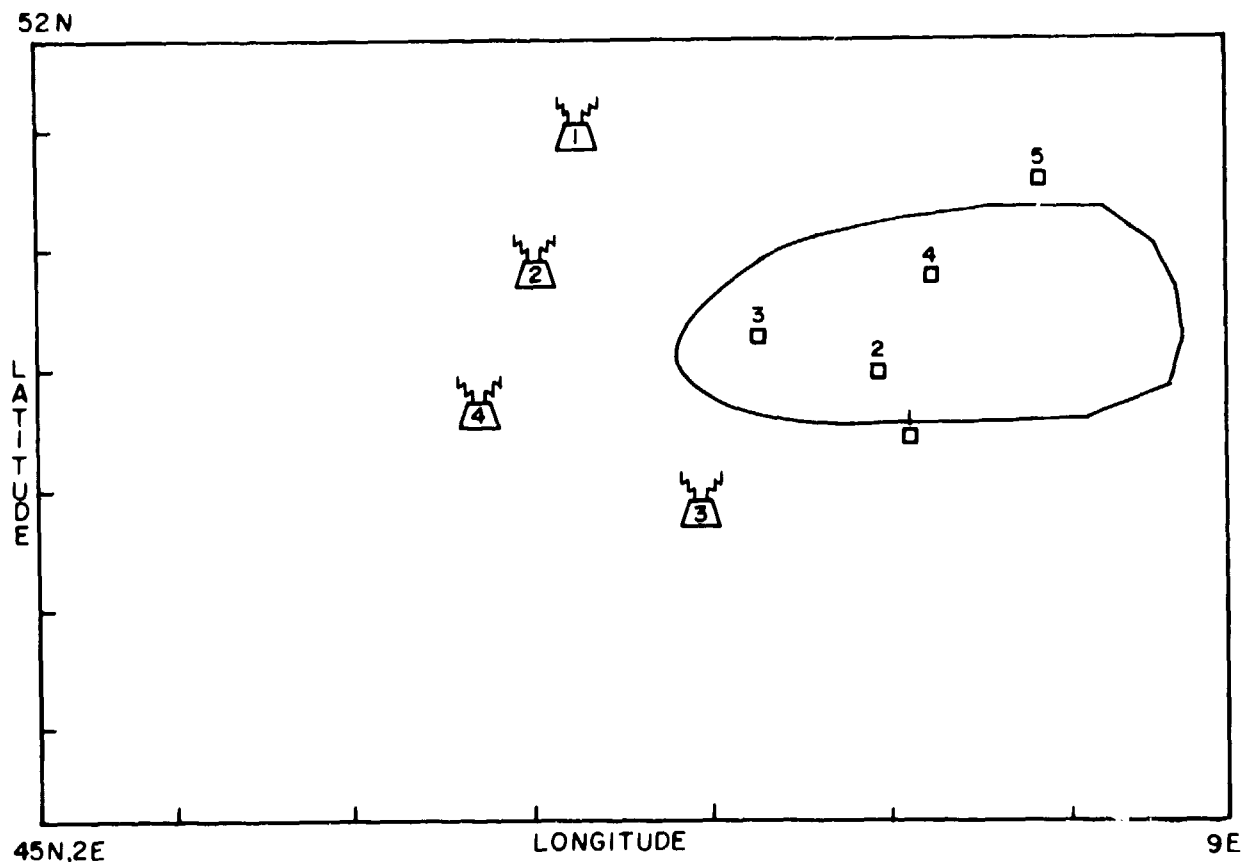
Figure 8: Link Analysis

Figure 9: Partial Overlay

VII. CONCULSIONS

The primary ingredient incorporated into this many-on-many COMJAM Model was flexibility. The user can build numerous scenarios from one-on-one to as much as 20-on-50. The graphic output enables the user to display the analysis results to his/her specifications. This many-on-many COMJAM Model is continually being improved and modified. Direct map overlays, incorporation of terrain data, antenna pattern considerations, and more, hopefully will be incorporated in the future. This model is but a first step towards a Network Analysis capability using a desk-top-computer.

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STANDARDIZATION OF COMMUNICATIONS JAMMING ANALYSIS

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SUMMARY

This paper uses a single channel, amplitude modulated, VHF/UHF radio system to point out the variations in parametric data for equipment elements, and the uncertainties of propagation analysis, and J/S ratios. Standardized methodology is expected to ease comparisons between systems and may lead to measures of merit for comparing communications jamming against other elements of force.

PROPOSAL FOR STANDARDIZED COMMUNICATIONS JAMMING ANALYSIS

The effective intergration of modern combat forces establishes the requirement for both the communications equipment to achieve adequate command and control, and the jamming equipment required to deny a belligerant force the communications they need. Each proposed system is subjected to a multitude of evaluations, studies and tests at virtually all phases of design, development, testing and operational evaluation. Even after the equipment is purchased additional tests are conducted to investigate the feasibility of new operational concepts.

At each stage where an evaluation is made is appears the purpose of the evaluation is different, the analyst is different, the manner (technique, tacit assumptions, rules-of-thumb, etc.) is different, and the form of data input and output presentation are nearly as unique as fingerprints, Any future analyst is faced with such a wide variety of different products that an evaluation of a single system is difficult even where the same data is used and the conclusions are the same. Comparing different systems is nearly impossible.

A standard methodology is needed for communications jamming analysis to minimize the variation in units for data presentation, and the manner of presenting both input data and results. It is also needed to minimize the variety of techniques used to compute and present results. Standardization is an enigmatic phenomenon: it is simultaniously considered to facilitate progress, and to be the antithesis of innovation. The pro's say it accellerates accomplishment, while the con's say it inhibits creativity. No one wants to be pushed into it, but we demand it of others.

A standard methodology need not imply identical. The best approach may be to provide the analyst with a variety of "off the shelf" alternatives which he could assemble to provide the best approach to an immediate problem.

At the system level of evaluation the use of a consistent methodology could provide the basis for evaluation of communications or jamming systems in terms of good, better, and best. It may also form the basis for evaluating electronic countermeasures against the more common force elements such as tanks, planes, ships and guns. The AFEWC expects to evolve into a modeling capability which will ultimately provide a field commander with a go/no-go answer, or more pragmatically with a probabalistic answer which takes advantage of his experience to recognize the odds that a tactic, or force mix will work, and balance the cost against the objective. The systems level evaluation would be a natural follow-on to the more elementary constituent analysis.

The most common and most often performed constituent analysis involves a single transmitter, a receiver and a jammer (a TRJ TRIAD) as such it will be the analysis considered for a standard methodology. The techniques and methodologies for most C3CM Analysis Models are aimed primarily at link assessments. Although these assessments may be credible they are based on nonstandard methodologies, Many are based on the techniques of an individual analyst and while there is nothing improper about this, a standardized methodology would promote communication between users, facilitate understanding, reduce cost, and permit pairing to accelerate project completion.

Writing an evaluation could be as simple as "Analysis of the AN/XYZ-12 was performed using standard methodology #1A, modified to use the Longley-Rice Propagation Model." The writer has replaced ten to twenty pages of methodology explanation with a single sentence. The reader is no longer tasked to trudge through page after page of equations constantly referring back to the definitions of variables, because this author uses Hebrew script exclusively. Deja Vue.

The micro-elements of constituent analysis include the TRJ TRIAD, their associated antenna systems, and the medium in and through which they operate. We will limit this discussion to the elements involving spectrum dependent radiating systems. Even the subject of communications jamming is too broad so we will not consider data link, or other digital systems, and manual morse is sufficiently different from

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voice that it should be addressed separately.

The Datalink Vulnerability Analysis (DVAL) Joint Task Force (JTF) has been established at Kirtland AFB, N.M. to develop a standardized methodology for digital communications system analysis.

Jamming effectiveness is often based on the ratio of jamming signal strength to transmitter signal strength required to sufficiently degrade communications. The basic equation used to model the TJR TRIAD for achieved jamming to signal ratio is:

$$\frac{J}{S} = 10 \text{ Log } \frac{Pj}{Pt} + Gj-Gt+Grj-Grt+10 \text{ Log } \frac{Br}{Bj} -Lj+Lt$$

Where Pt = Transmitter Power (Watts)
       Pj = Jammer Power (Watts)
       Gj = Jammer Antenna Gain (dBi)
       Gt = Transmitter Antenna Gain (dBi)
       Grj = Receiver Gain Toward Jammer (dBi)
       Grt = Receiver Gain Toward Transmitter
                                         (dBi)
       Bj = Jammer Bandwidth (KHz)
       Br = Receiver Bandwidth (KHz)
       Lj = Propagation Loss for Jammer (dB)
       Lt = Propagation Loss for Transmitter
                                          (dB)
Note: $0 < (Br/Bj) \leq 1$
       J/S = Ratio of Jamming to Signal Strength
                                          (dB)

Each of the equipment elements have parametric data associated with them and each data element can be expressed in a variety of ways depending on the source. In addition each of the parametric elements have associated with them a certain deviation. We will consider each significant equipment parameter.

Antennas:

There are many antennas which, when the physical dimensions are known, can be modeled with reasonable accuracy. Even the effective dimensional changes due to end effect and altered phase velocity can be taken into account. However, the antenna data normally available is "Gain", and "Beam Width". The gain may be in dB referenced against a $\frac{1}{4}$ λ dipole, a $\frac{1}{4}$ λ verticle radiator over a metallic ground plane, a 5/8 λ verticle radiator over a metallic ground plane or an isotropic source. Fortunately these can be converted from one frequency to another without a lot of trouble.

Most analysis reviewed by the AFEWC use the antenna gain given (boresight gain) for the full beamwidth, where beamwidth is measured to the half power points. Thus we start out in our analysis with a potential for up to 3 dB error.

It seems that we could agree on some semi-

simple algorithm which could reduce that error.

Transmitter:

Even a simple plate modulated, class C final, AM transmitter can prove difficult to model with tremendous accuracy. Radiated frequency is fairly predictable, stable, and well behaved. Radiated power 's another case. The AN/GRC-27 is rated with a nominal power output of 100 watts. In normal day to day operation it would frequently deliver anywhere from 150 up to 210 watts. This is a deviation of about 3 dB from the specifications. An Army field radio is rated at 4 and 12 watts output; switch selectable. During tests in 1979 it was found that, in the low power position, the set would put out anywhere from 2 up to 9 watts, and in the high power position the output was from 6 up to 15 watts. This is a deviation of from about -3 dB to +3 dB.

Modulation:

This mechanism is often taken for granted since it is so well understood by design engineers. The number of technicians who understand the phenomenon are somewhat rare. This may help to explain why so many transmitters have sloppy modulation. Just a little overmodulation, or deterioration in the power supply can distort the audio intelligence and diminish the transmitter effectiveness. This term does not show in the J/S equation.

Receiver:

Receiver sensitivity is probably a good measure of merit. Here, however, you have a wide variety in the form of the specifications. Sensitivity may be given as:

    Noise Figure
    Tangential Sensitivity
    Minimum Discernable Signal
    Microvolts for a given S/N ratio
    dBm for a given (S+N)/N ratio

The receiver may incorporate any of several AVC designs (straight, delayed, delayed and amplified, delayed and amplified with forward feed), manual R.F. gain control, squelch circuit, and noise limiters of which there must be at least a dozen basic circuits, and multiple variations on each. The bandwidth and effective noise bandwidth can vary due to design or age. Adding preselectors, and bandpass filters all combine to increase the difficulty of modeling even a common AM communications receiver.

Jammer:

The jammer is similar to the transmitter; The remarks on frequency, power, and modulation for the transmitter apply equally to the jammer.

The principle differences are in the area of control and power management. Whether a jammer is tuned manually or automatically can have a profound affect on its suitability for employment in tactical situations. Likewise, the method of power management is also important. The analysis techniques for dealing with power sharing are relatively straight forward, but those for dealing with time sharing are not so well understood.

As an example, consider a time shared jammer with a peak CW power of 500 watts. This jammer is attacking four different radio links. Clearly the average power directed at any one link's receiver is only 125 watts. Yet when the jamming is present the receiver "sees" the full available jammer power of 500 watts. The question of which of the two power levels to use in an analysis has not been easy to answer. Probably neither is correct. The real answer will require specific data on timing, modulations, and J/S ratios required. The difference between the two power levels is 6dB.

Propagation:

The medium of transmission is the atmosphere, and we can predict its effect on any given day about as accurately as we forecast weather. Even limiting ourselves to the UHF/VHF bands where propagation is essentially line-of-sight we have a wide variety of propagation analysis techniques available which vary from pure theoretical to pure empirical.

Four of the propagation models which could be used for predicting atmospheric losses are:

TIREM - Terrain Integrated Rough Earth Model.

IPS - Integrated Propagation System

Longley - Rice

EPM-73 - Empirical Propagation Model, 73

The first three are big, sophisticated models while EPM-73 is fairly small and fits on a microcomputer. We have used EPM-73 mainly with frequencies between 30 and 2000 MHz. According to the literature this model provides answers that are essentially equivalent to those of larger models. Yet the calculated values for propagation losses for these large models may vary from each other by as much as 5 to 7 dB. EPM-73 tends to fall into the middle of this range of values. However, the standard deviation about the mean value that all of these models compute can be as much as 12 to 20 dB, depending upon frequency.

In addition, two authoritative and reputable organizations in the propagation business hold divergent views on the validity of a particular model and on the procedures for handling the empirical data used to validate it. The number of opinions you can get on the suitability, accuracy and limitations of any given propagation analysis technique is about equal to the number of experts in the field.

The J/S Ratios and Intelligibility:

A required J/S ratio is perhaps the most popular EW performance measurement used in a basic TRJ TRIAD analysis. However, we are implicitly using some measure of INTELLIGIBILITY DEGRADATION. That is, for a hypothetical system, a J/S ratio of -3 dB would be required for a 50% reduction in intelligibility.

Relationships between J/S required and intelligibility are not consistent from source to source. Many are based on standard (NON MILITARY) subject testing in laboratory environments using balanced-word lists, random character readings, rhymed word lists, or scripted transmission scenarios. While derived intelligibility factors may be based on single character, single word, or concept and idea recognition, the J/S ratio required in military operations is a function of the intelligibility necessary to complete a particular task or mission.

Bell Labs discussed these problems as early as 1944, relating them to the human hearing mechanism and its tolerance to various jamming tactics. They found that:

* Interfering noise is effective only if its frequency and intensity is comparable with those of speech.

* A single tone can mask frequencies within about 100 to 200 Hz so that the jamming signal must consist of a continuous spectrum of closely spaced discrete frequencies for effective jamming.

* A pulse must last at least 200 msec before the ear stimulation is equivalent to that of sustained tones. Short pulses are less effective than continuous types of jamming signals. Recall our previous discussion of Time-Shared jamming systems and you can see how the Bell Lab's work may relate.

Bell Labs also found that:

* High level pulses can impair reception due to momentary deafening, but is easily fixed by clipping, suppression, or frequency limiting filters.

* A listener can recognize 60 to 70% of the words transmitter when 150 msec of each 187 msec time interval is deleted, although we haven't

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learned yet the method used by Bell Labs for this test.

The office of Telecommunications and ECAC jointly published "The Communications Electronics Receiver Performance Degradation Handbook", 2nd edition, in support of ESD. The handbook has a series of graphs which clearly show that a S/Interference ratio from 0 to 8 dB is required for satisfactory reception with a receiver output S/N ratio of 20 to 25 dB.

There are other rules of thumb, or pseudo-standards, as well:

* It appears from several reports that the Army prefers a J/S ratio of +6 dB to insure adequate jamming intensity.

* A briefing prepared by Sanders Corporation on a time-shared jamming system suggests that a J/S ratio of 0 dB is appropriate for that type of system.

* From an analysis of Red and Blue Flag exercise data, we find that a J/S ratio of -11 dB provides effective jamming against some systems, while other systems required a J/S ratio of +6 dB. That is a total spread of 17 dB UNCERTAINLY.

In addition to the effects described above, some jamming modulations are designed to stress psychological as well as physiological irritation on the human receiver. These would be expected to become more effective over time.

The proposal is that we begin in a certain well-defined area such as standard AM communications. That we investigate this one mode and establish the units to be used in presenting data, that we specify the techniques to be used in accounting for each of the micro-elements, and that we describe the manner in which output data will be presented. The first and possibly simplest area may be the VHF/UHF region, single channel, AM communications system.

There is no doubt that the many uncertainties involved will leave any theoretical analysis somewhat short of perfection; however, in the comparison of different systems the common errors will work against both systems equally

well (or bad) and minor deviations will cancel each other.

The Air Force Electronic Warfare Center is keenly aware of the requirement for standardized methodology. We have conducted extensive tests in conjunction with the Aeromedical Research Laboratory to evaluate J/S ratios against intelligibility in that area, evaluate jamming modulations, account for training, skill, aptitude, individual voice quality, hearing ability and provide supporting documentation for the J/S values used in our evaluations, We have adopted the use of ECAC's EPM-73 propagation model and we are working at standardizing the kinds and form of output data presentations we use.

No analyst should be expected to subordinate his abilities or imagination for the sake of standardization but as a minimum regardless of whatever other analysis technique may be used, we need a standardized methodology as a baseline approach for comparison and for reproducibility of results.

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SEEK TALK - A JAM-RESISTANT TACTICAL COMMUNICATIONS SYSTEM

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Communications play a vital role in the Force Multiplier concept of modern defense strategy. The seriousness with which potential adversaries view our use of communications in this role is amply illustrated by their determination to field effective Electronic Countermeasures systems to disrupt battlefield communications, and to control the communications spectrum to their own benefit. An example of this determination occurred during the 1973 Arab-Israeli conflict, where Egyptian-operated UHF jammers significantly degraded Israeli air operations. It is clear that the UHF communications band, widely used for tactical air, sea, and ground forces for command and control purposes, is vulnerable to jamming as long as the radio equipment remains unprotected. (See Fig. 1.)

- UHF Voice Communications Can Be Rendered Useless By Opposing Force Jammers

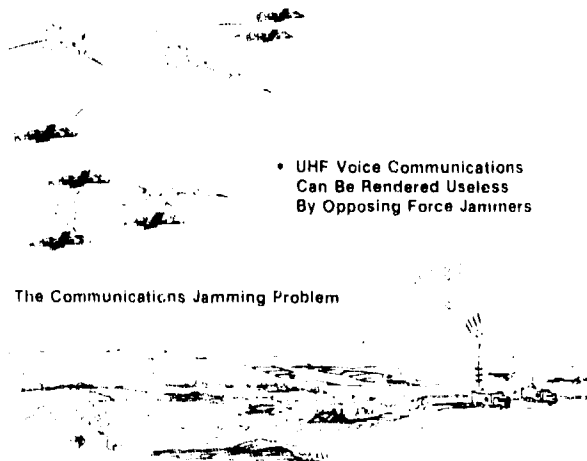The Communications Jamming Problem

Fig. 1. The Communication Jamming Problem

The degree to which this vulnerability exists can be given in generic, unclassified terms. Suppose a command and control aircraft is attempting to communicate with fighters under its control, and an enemy jammer is located 150 miles away. The communications range is limited in this example to just 25 miles (Fig. 2). The assumption made is that the jammer is ten times more powerful than the radio transmitter -- certainly a conservative assumption given today's jammer technology versus the typical airborne transmitter.

The solution to this problem is to incorporate jamming resistance into the radio systems. Without specifying how it is to be done, let us assume that 15 dB (Fig. 3) of jamming protection is added to the radio terminals on both ends of this command and control link. Now, it is possible to communicate to the fighter up to a range of 80 miles from the command and control aircraft, or 70 miles from the jammer. Communications from the fighter aircraft back to the command and control can take place when the fighter is 170 miles away, or just beyond the jammer itself.
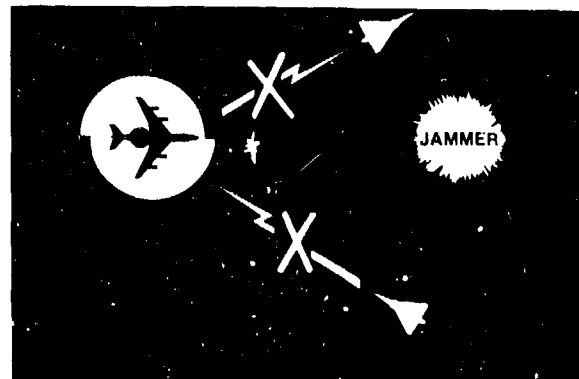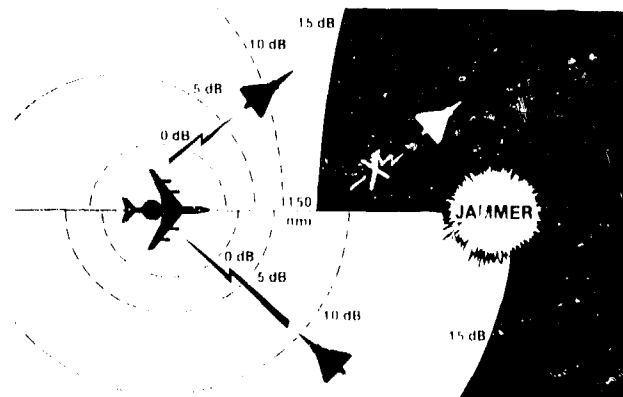

Fig. 2. Communications Range No Jamming Protection

Fig. 3. Communications Range 15 dB Jamming Protection

Adding 15 dB more jamming protection (Fig. 4), communications can take place to the fighter when it is within 25 miles of the jammer, and the link from the fighter back to command and control is essentially unimpeded. It is apparent that aircraft operating in the near vicinity of enemy jammers need more anti-jamming (AJ) protection than those further removed.
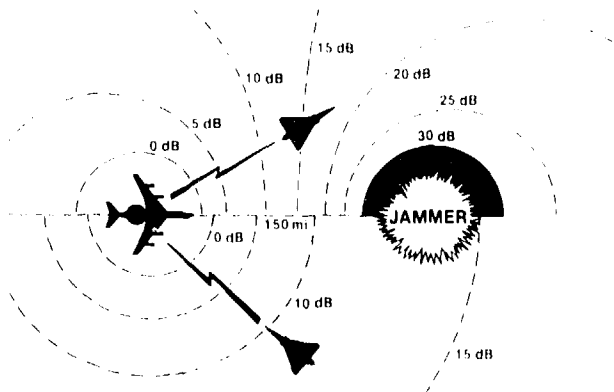
Fig. 4. Communications Range
30 dB Jamming Protection

The protection of communications systems against undesired interference is not a new concept within the communications scientific community. However, the cost associated with the electronics needed to implement such systems has been prohibitive prior to the advent of low cost digital and analog LSI devices, along with other specialized devices such as SAW and CCD correlators. It now appears that both the cost and the size of practical jam-resistant communications systems can be driven low enough to permit wide deployment to tactical air, sea and ground forces. (See Fig. 5.)
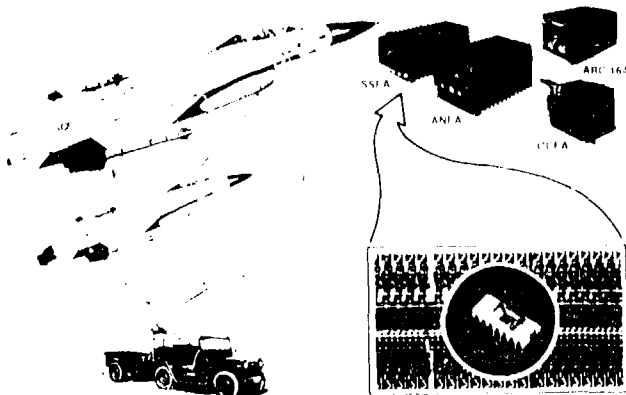

Fig. 5. Spread Spectrum AJ Radios with CCD Correlation and Other LSI

The SEEK TALK program was initiated in 1976 by the U.S. Air Force, to fill the urgent need for jamming protection in the UHF communications band, through the use of the latest technology (Fig. 6). The waveform selected is a direct sequence pseudonoise spread spectrum waveform, and this is combined with adaptive nulling antenna techniques for those aircraft requiring a higher degree of AJ protection than that offered by the waveform alone. The selection of

this combination of technologies and the architecture of the system is derived from the requirements of tactical voice communications.
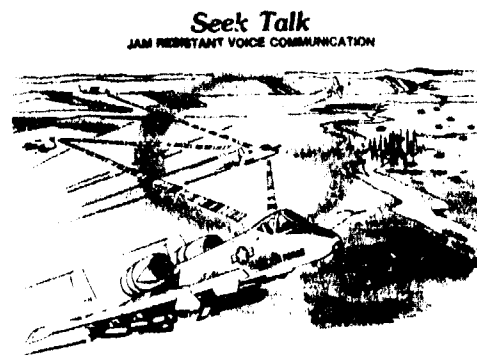

Fig. 6. SEEK TALK Jam-Resistant Voice Communication

Tactical Air Combat consists of high speed, high stress situations, where pilots depend significantly on instantaneous voice communications to successfully complete the mission, while staying alive (Fig. 7). Close proximity to friendly troops, where confirmation of targets is essential, and wing-man support in counter air operations, are examples which drive the requirements placed on tactical radios. The need is for highly reliable communications that allow for instant access, multiple signal reception, break-in for urgent messages, and which are securable and backward compatible with unprotected or interim AJ systems such as HAVE QUICK. (See Fig. 8.)

■ Multiple Conversations with Short, Clipped Messages

■ Urgent Break-In for Warnings

■ Gives Pilot the "Big Picture"

Fig. 7. Tactical Voice Communications

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- **Jamming Resistant (Spread Spectrum and Adaptive Array)**

- **Conferencing (Break-In)**

- **Compatible with Encryption Devices**

- **Operator Transparency**

- **Mode Selectable**
  - **Clear AM**
  - **Jam Resistant Conferencing**
  - **COMSEC**

Fig. 8. SEEK TALK Characteristics

Fig. 11. Filtering Approach

In addition to providing the required performance characteristics, some consideration is given to the impact upon the UHF spectrum by the deployment of an operational SEEK TALK system. Frequency hop waveforms can easily traverse the entire spectrum, imposing an intermittent interference upon all other users (Fig. 10). Even more significant is the cosite location of multiple AJ radios. With SEEK TALK, the limited waveform bandwidth allows the continued use of high performance, mechanically tuned filters (Fig. 11) to permit independent multiple network operation at command and control sites or on command and control aircraft. This limited band of operation is possible because part of the AJ protection for SEEK TALK is provided by the adaptive array, which is not dependent upon the amount of band spreading in the waveform.
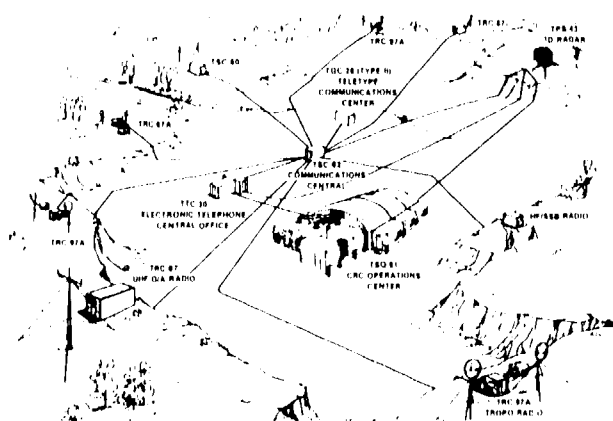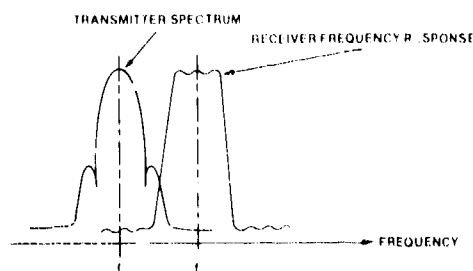
A number of equipments related to SEEK TALK have been developed and tested by General Electric. This brassboard unit (Fig. 12) was the first to demonstrate the concept of break-in conferencing with a pseudonoise spread spectrum waveform. It utilized an early version of the GE charge coupled device (CCD) correlators. A field demonstration of this unit was conducted using modified AN/GRC-171 radios (Fig. 13). All of the basic concepts were tested, including jamming resistance, break-in, signal acquisition, transmission security, and radio interface.

An adaptive nulling antenna brassboard (Fig. 14) was also developed and tested. This was a four-loop version and proved the basic compatibility of the nulling processor with the spread spectrum waveform. Range tests using various antenna configurations were conducted, and tested using ground planes, and on the skin of actual aircraft (Fig. 15) shown here at the Newport range of Rome Air Development Center. Griffiss Air Force Base, New York
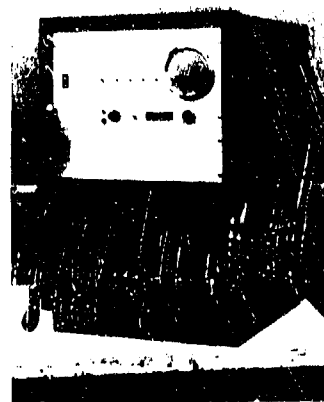
Fig. 10. Cosite Interference

Fig.12. Communications ECCM Brassboard

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■ JAMMING RESISTANCE

  • Jammed AM Channel
  • Clear Reception in Spread Spectrum Channel
      (Same Jamming Power)

■ BREAK-IN

  • Establish Link with One Transmitter
  • Second Transmitter Comes in on Top

■ SIGNAL ACQUISITION

  • Oscillator Stability Allows Extended Time Before Resync.
    Once Initialization is Performed
  • Sync Reset Demonstrated

■ NONREPEATING CODE FOR TRANSMISSION SECURITY

  • Four-Minute Code is Effectively Nonrepeating from Processing Standpoint

■ INTERFACE

  • AN/GRC-171 Interface at Audio and IF. Stable Local Oscillator Provided

Fig. 13.   Demonstration Significance
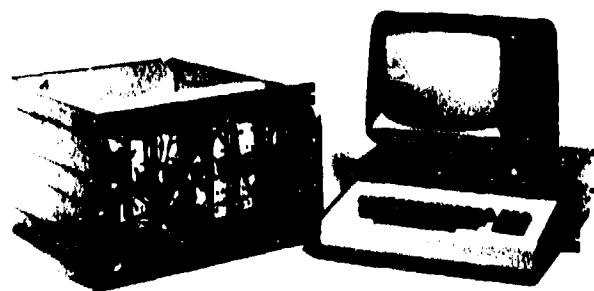
Fig. 14.   Adaptive Nulling Antenna
Brassboard

Fig. 15.   A-10 at Newport Range

Under contract to RADC, a flyable
Advanced Development Model of the SEEK
TALK equipment was designed and fabrica-
ted.   Initial flight tests took place
recently on this T-39 aircraft (Fig. 16)
operated by the 4950th Test Wing, flying
out of Griffiss Air Force Base.

The Spread Spectrum Modem (Fig. 17)
is shown here installed in the aircraft,
along with the AN/ARC-164 UHF radio.
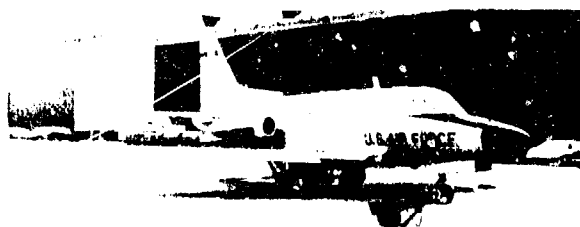
Fig. 16.   Flight Test Aircraft
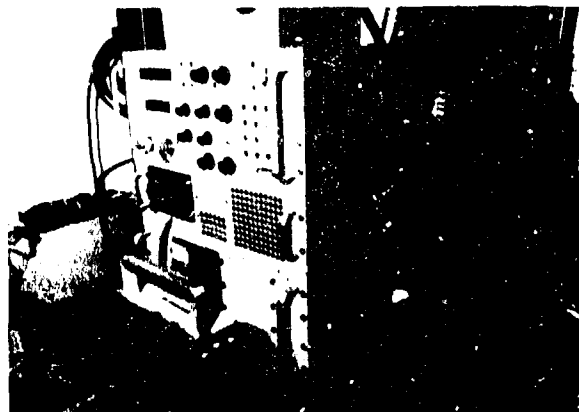
Fig. 17.   Flight Test Modem

These units make up the Adaptive
Nulling Array Processor (Fig. 18).   As
can be seen, considerable control flexi-
bility is built into the ADM units, so
that parametric optimization can be per-
formed during the test series.   Also on-
board the aircraft is a test sequencer
and recorder to record both voice and
digital data as the units are sequenced
through their various modes and perform-
ance comparisons are obtained.   These
tapes are analyzed later to obtain de-
tailed parametric data.
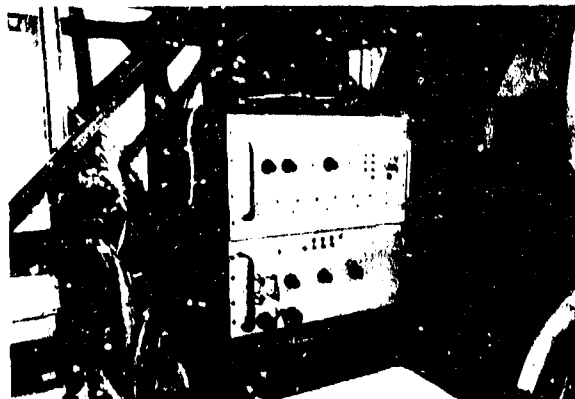
Fig. 18.   Antenna Nulling Processor

This signal simulator (Fig. 19) is a specialized piece of test equipment built especially for the SEEK TALK ADM. It incorporates several simultaneous transmit channels for signals and jamming, individually controlled as to apparent range and velocity. It can be used for laboratory testing, and also has a high power transmit channel for use in field testing.
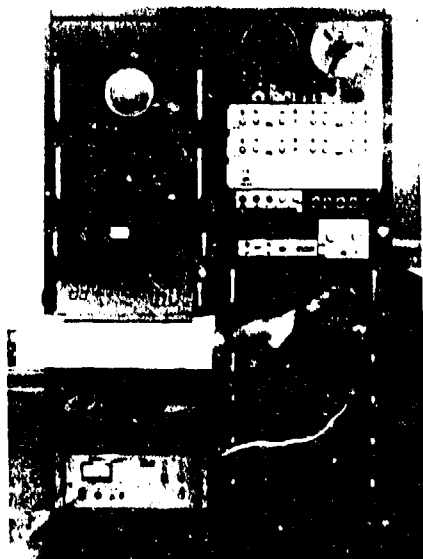
Fig. 19.   Signal Simulator

Flight tests flown at Griffiss (Fig. 20) used jamming sites at Camden, Ava, and Forestport. Communication sites were at Griffiss AFB and the GE plant in Utica. Successful test results were obtained using spread spectrum and adaptive array jamming protection, individually and combined. The jamming transmitters used in these tests would have made communication with unprotected radios totally impossible.

The Full Scale Engineering Phase was recently initiated by AFSC, Electronic Systems Division, Hanscom AFB, Mass. Under the program, fully qualified production prototypes will be designed, built, and tested. (See Fig. 21.) The airborne tests will be on board F-16 and OV-10 aircraft, while ground units will be installed in the AN/MRC-107A (jeep) and in the AN/TPS-43 radar control shelter.

As shown on this overall program schedule (Fig. 22), delivery of FSED units is expected in mid-1983, with Low Rate Initial Production units delivered in late 1984 or early 1985. The SEEK TALK program will provide the U.S. Air Force with reliable voice communications in jamming environments, and will provide the basis for interoperability with other Armed Forces of the U.S. and our NATO Allies.
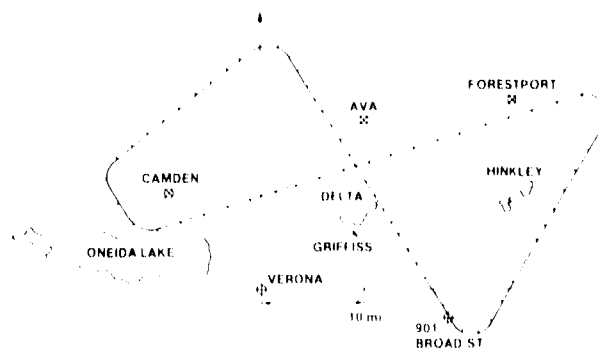
Fig. 20.   Flight Profile No. 4
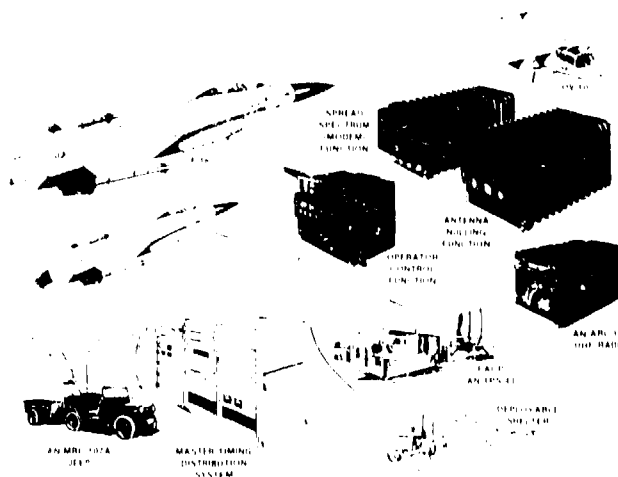
Fig. 21.   Full Scale Engineering Development (FSED) Equipment
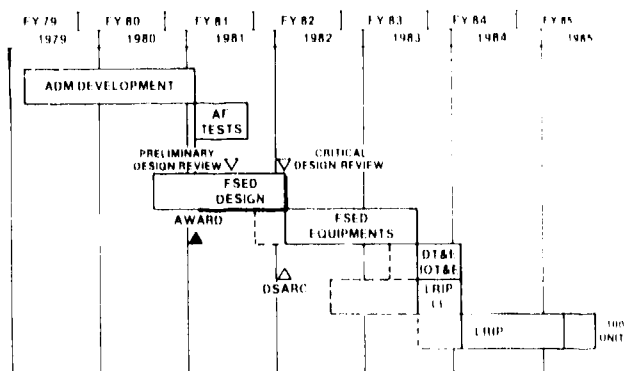
Fig. 22.   GE SEEK TALK Program Overview

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**SESSION III
"ELECTRO-OPTICS AND MILLIMETER
WAVE TECHNIQUES"**

Chairman: Colonel Joseph Pollard
Commander and Director
Office of Missile Electronic Warfare

C^3I APPLICATIONS FOR FIBER OPTICS

Donald B. Brick, ESD/XR
Brian Hendrickson, RA C/DCCT
Andrew Yang, RADC/ESO

ABSTRACT

Fiber optics is gaining increasing interest as an alternative to cable in Air Force command control, communications, and intelligence systems not only because of its bandwidth, low loss, and cost advantages but also the potential for enhanced survivability and EMP, jamming, and intrusion resistance.

This paper will emphasize ongoing and planned Air Force efforts to introduce optical fibers into tactical C^3I applications. Technical discussion will focus on efforts to replace metallic cable; introduce bus (multi-terminal) systems; intrusion, EMP and jamming resistant and more-survivable communications; new multiplexing techniques; and efforts at standardization.

ELECTRONIC WARFARE MILLIMETER WAVE
TACTICAL AND STRATEGIC APPLICATIONS

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ABSTRACT/SUMMARY

It is becoming increasingly recognized that Electronic Warfare (EW) plays an important role against enemy missiles, radars, weapons systems and communications and is extremely effective in the defense and protection of modern ships and aircraft. Jamming and deception become even more important as increasingly complex and more "smart" weapons using sophisticated guidance methods are developed. Most of these complex weapons have a high "Kill" probability if they are not jammed, deceived or destroyed either by "Hard or Soft" kill techniques.

In compiling this paper for presentation, a search of both open source and available intelligence community classified documents was conducted in an attempt to assess free world and communist block millimeter wave applications technologies. The research included past development, component performance, previous development, deployment tactics, future and present research trends, and applications of millimeter wave technologies. The technology assessments were evaluated as to engineering and operational feasibility and soundness, in terms of both millimeter wave component and system applications.

The results of the literature search and evaluation effort led to the generation of a Soviet/ Communist block millimeter wave threat assessment and technology presentation. This presentation includes past, present, and future Soviet technologies and projected applications of these technologies in the millimeter wave region of the radio frequency spectrum. In areas where specific comparisons of Soviet technology could not be confirmed due to lack of available information, the Soviet technology was assumed to be on a level par with that of the United States and other free world countries, so that potential millimeter wave threat assessments could at least be speculated.

A millimeter wave propagation analysis through 300 GHz was compiled and included in the presentation for reference and for consideration in the evaluation of millimeter wave applications.

A threat assessment of signal parameters, applications, functions, and a battlefield scenario using Western Europe in a worst case situation was described and assessed. Future system utilization and deployment of the hostile signal environment in the millimeter wave spectrum was postulated and evaluated from both a tactical and strategic viewpoint and formed the basis for a Hughes Aircraft computer generated scenario to simulate these environments, signal functions, applications and densities. This simulation is currently used in the design of systems being developed for use in the millimeter wave region.

Speculation of deployment and tactics of Soviet forces using millimeter wave non-communications systems was developed along with Electronic Countermeasure (ECM) and Electronic Support Measures (ESM) collection requirements which address the intercept and countering of active hostile radars and weapons systems. This effort required research of active ECM components, antennas, and jammer development along with present ECM/ESM platform capabilities. Mission requirements of various platforms were also discussed along with the land-based battle environment of the 1990 time frame. Exotic signal considerations, requirements, and potential deployments in the millimeter wave region were developed on the basis of current Soviet doctrines and tendencies.

Considerations for future Friendly nation surveillance systems for this frequency band were assessed and considered, including the requirement for battlefield support equipment and systems. A cost, weight, and size assessment was made along with the antenna, receiver, and processor technologies and requirements.

Study and research efforts were also concentrated on direction finding and processing techniques, primarily in the 18-40 GHz range, which could be compatible and capable of interface with current microwave receiving/analysis systems in the attempt to minimize cost. Multi-beam antenna and amplitude comparison direction finding techniques were found to be most advantageous in this frequency region. These approaches were found highly suitable for high emitter densities, are adaptable to signals with "exotic" characteristics, and can achieve direction finding accuracies of better than one degree.

ARM SEEKER COUNTERMEASURE TESTS, PART II

by
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ABSTRACT

The NSWC effort in ARM-CM continues. In the past year, static field testing at a radar site using the recommended countermeasure tactics has verified compatibility with the radar and effectiveness of the tactics. Dynamic field testing has also occurred using an aircraft carrying an ARM seeker making simulated missile approaches against a radar and a nearby decoy. The tactic was again successful in transferring acquisition from radar to decoy, and conversely, when the proper tactic was not used, a high probability of radar hit occurred.

SUMMARY

The measurements of SHRIKE seekers by NSWC in an anechoic chamber, presented at the previous symposium were sufficient to determine significant seeker characteristics and to identify potential counter-ARM tactics. It was decided to proceed with field testing using geometries typical of actual missile engagements. A plan for a static field test was written for the NRL/Chesapeake Beach site where several test assets not otherwise available in the local area could be found. These included: a modified SPS-39 radar with external AM inputs, a transmitter to simulate the decoy which could be remotely sited and controlled, and the NRL jack-up barge, which furnished a moveable platform from which the SHRIKE seekers could view the target emitters.

A number of radar and decoy transmissions were investigated with the following results:

(1) It was possible to track air targets with occasional short interruptions in radar operation.

(2) It was possible to distinguish air targets in the presence of decoy-produced interference.

(3) The favored tactic was successful in transferring acquisition from radar to decoy.

(4) Multipath of target emitter signals made it difficult to achieve quantitatively comparable results as geometry and sea state varied.

The next field test effort proposed was a dynamic simulation with an ARM seeker mounted in an aircraft representing missile approach to the target. Although results obtained from the static field test at NRL/Chesapeake Beach were encouraging, limitations of the available facilities forced a change in location to NWC, China Lake for dynamic testing. A test plan was developed which used a TA-4J aircraft, based at NWC, carrying the Flyable Generic ARM Seeker (FGAS) to simulate the threat missile. The FGAS has a number of selectable discriminants including angle, frequency search, PRF, pulse width, and signal intensity.

In the dynamic field test the radar and decoy emitters were separated by a distance typical of suggested tactical usage. The aircraft approached the target area in a direction perpendicular to the axis between the two emitters. The aircraft dived at the target area at angles up to those typical of threat missiles. Various target emission formats were used to identify successful and unsuccessful tactics. Data was collected by means of telemetry of seeker operation and by video tape of the target area as seen from the aircraft. A total of 74 aircraft passes were made, and the favored tactic was successful in 24 out of 24 passes in which it was used. Other tactics were only partially successful or completely unsuccessful in transferring acquisition from the radar to the decoy.

POTENTIAL OF ELECTROMAGNETIC
ENERGY FOR WEAPONS APPLICATION

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Electromagnetic energy possesses a very real potential for functional impairment and/or destruction of certain targets. The purpose of this paper is to explain that leading statement.

Whenever electrons are forced to oscillate in a suitable medium, electromagnetic waves are produced. These waves are described by Quantum Mechanics as having both "wave like" and "particle like" characteristics. The "particle like" packets are called photons and possess a discrete level of energy described by the formula E=hf where h= Plancks constant and f= frequency. Energy amplification by stimulated emission of radiation has been well exploited in the infrared to ultraviolet portion of the electromagnetic spectrum. However, this paper will deal primarily with the microwave portion.

Microwaves are electromagnetic waves emanating from the frequency domain of 30MHz to 300GHz of the electromagnetic spectrum. The energy possessed by these waves (or photons) can interact with certain target characteristics in a detrimental way. For instance, they can interact with the electric dipole moment of the H_2O contained in human tissue molecules and by causing this dipole moment to constantly realign itself with the oscillating electric field of the wave, produce heat. The heat generated by such interaction then acts to damage the tissue.

Antipersonnel effects generally fall into two broad categories of nonthermal and thermal. Nonthermal effects include psychological impairment and other subtle debilitating effects. Due to a lack of controlled, long term studies in this country, many U.S. scientists are skeptical about the potential psychological effects of human exposure to RF energy. No such skepticism, however, exists in the Soviet Union. Their view is that definite psychological effects do occur. Perhaps that explains their bombardment of the American Embassy in Moscow with low level microwaves a few years back. At any rate, they have established a minimum safe exposure level that is 1000 times less than ours. Experiments conducted with Rhesus monkeys in this country concluded that "Exposure to microwaves was found to decrease performance rates directly proportional to field intensity and exposure time." Power levels used in this experiment

were from 3-13 mW/cm^2. Such effects, if conclusively demonstrated could have enormous significance to pilots of high performance aircraft.

The thermal effects include skin sensation of heat, cataracts, 3d degree burns of skin or internal organs and/or death. The U.S. Army Medical Research Laboratory has conducted tests on burns with microwaves producing 3d degree burns on human skin with 20 W/cm^2 for 2 seconds. Results such as this and other studies indicate that power densities of 20-80 W/cm^2 for 1 second may be lethal. Lesser injuries occur at much lower power densities (as low as .5 W/cm^2). The study from which this conclusion was extracted goes on to conclude that "personnel in vehicles are vulnerable because microwaves can pass through openings, glass or fabric with little or no attenuation. As long as the wavelength is not larger than the opening, the majority of the incident energy gets through although it may be diffracted."

Systems effects include functional upset of electronics, damage or burn-out of electrical components and structural damage. The most familiar manifestation of this phenomenon is probably found in the description of a nuclear electromagnetic pulse. One of the side effects of a nuclear explosion is the generation of an intense electromagnetic field incident to the earth's surface. Metallic objects (targets) immersed in this field will have electric currents and charges induced on their surface.

Army communications and weapon systems generally share electrical characteristics that make them effective couplers of EMP. Intentional openings, such as antennas and radomes as well as unintentional openings such as cables, wires, poor seals, etc., will allow the entry of these currents. Sensitive electronic components can then be upset functionally or even burned out. Some typical power levels necessary to achieve damage can be found in Figure 1.

Component	Minimum Energy
Microwave Diode	1×10^{-7}
Switching Transistor	5×10^{-5}
Rectifier Diode	6×10^{-4}
Relay	2×10^{-3}
Audio Transistor	5×10^{-3}

Figure 1. Minimum Energy Required for Burnout

There are also several theoretically possible techniques to cause actual structural damage. Security classifications do not permit further discussion in this paper. Figure 2 depicts some potential targets for microwave energy attack.

TACTICAL	STRATEGIC
PERSONNEL	AVIONICS IN
COMMUNICATIONS	MANNED BOMBERS
RADARS	CRUISE MISSILE GUIDANCE
RPV'S	ICBM'S
AIRCRAFT	SATELLITES
COMPUTERS	REENTRY VEHICLES
FUEL STORAGE SITES	
MISSILES	
ELECTRO-OPTICS	

Figure 2. Potential Targets for Microwave Energy Attack

There are currently several approaches under active development in the Soviet Union to beam microwave energy, much in the manner of a laser, which would allow sufficient power deposition on target to cause the effects heretofore discussed. Combat vehicles, as currently designed, do not provide adequate protection against electromagnetic energy attack. Vision blocks are transmissive to wavelengths approximating the size of the opening.

Some of the known approaches include: CYROCON - An RF generator with the potential for very high powers and efficiencies for either CW or pulsed operation. REFLEX TRIODE - Another technique for generation of very high output power. Harry Diamond Laboratory recently achieved over 1 GW output in experiments conducted there. The Soviet model is assessed as having the potential for power output on the order of 10^{12}W. GYROTRON - A device that uses the cyclotron resonance effect to convert the kinetic energy in an electron beam to MM wave radiation in the 30 to 300 GHz range.

Perhaps one of the most significant Soviet developments to occur recently is the building of a magnetron amplifier which can amplify an external signal by about 30dB. A 30dB signal amplification is equal to a gain factor of 1000. Only a little imagination is required to connect this development with the high power generators discussed previously and draw some conclusions regarding weapon possibilities.

It is the conclusion of this author that the Soviets are continuing to explore the technology necessary for development of high energy microwave generators to be used in a directed energy weapon system. Additionally, the destructive mechanisms of such systems pose a very significant threat to personnel and systems. Finally, current technological developments in the U.S. such as advanced composites and microelectronics may well provide the Soviets the very doctrinal requirements needed to justify development of such directed energy weapons.

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ELECTROMAGNETIC COMPATIBILITY CONSIDERATIONS OF ELECTRO-OPTICAL WARFARE SYSTEMS IN A FRIENDLY ENVIRONMENT

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SUMMARY

Current DoD Electro-Optic (EO) Warfare programs are designed to assess and provide a technological response to specific categories of EO systems found in the hostile threat inventory. With the expected proliferation of EO devices, and the concomitant increase in EO countermeasures and counter-countermeasures efforts, the insurance of compatible operation of the EO device with other friendly and neutral RF and EO devices found in the same tactical environment is necessarily becoming a concern of various elements within the DoD. This paper addresses this concern and provides an overview of the newly emergent discipline of EO electromagnetic compatibility (EMC) in relation to developments in the field of EO warfare.

Until recently, little attention has been given the potential electromagnetic interactions between friendly electro-optic devices which could lead to degradation of system performance. Several early papers discussed possible mechanisms by which radiation in the optical portion of the electromagnetic spectrum might be coupled between an offending transmitter and victim receiver, but were rarely applied to the analysis of specific EO devices.

Recently, several preliminary EMC studies were performed by the electro-optics staff at IITRI/Annapolis Operations at the request of the program management offices responsible for the development of the XM-1 Main Battle Tank and the Combat Identification System (CIS). The results of these analyses indicate that the coupling of energy between friendly devices may occur via several principal coupling mechanisms, and may be quite probable under certain tactical and atmospheric conditions.

Our results prove to be complementary to those of other researchers involved in the intentional coupling of optical radiation into an EO device, viz. EO warfare. The circle will now be completed to include a discussion of the interactions possible between EO warfare systems and other electro-optic devices. This paper may serve to introduce a new, and necessary, dimension into the existing frame within which EO systems design and analysis is performed.

SESSION IV
"ELECTRONIC WARFARE TRAINING"

Chairman: Major General James E. Freeze
Assistant Deputy Director
for Plans and Policies
National Security Agency

EW TRAINING USING RADAR ELECTROMAGNETIC ENVIRONMENT SIMULATION
ABSTRACT

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This paper describes what is necessary in a simulator to achieve a high degree of operator competence in interpreting a radar display in a threat environment. The achieved level of operator competence is a function of the degree of realism and complexity created. The models used for the generation of the signatures of aircraft/missile/ship targets, chaff, sea clutter, rain and jammers, operating in a dynamically controlled environment, are described in detail. The hardware/software implementation and equipment installation, together with problems encountered during the simulator design are also discussed.

INTRODUCTION

Today's electronic technology can provide a realistic, accurate, and extremely flexible simulation of the electromagnetic environment compatible with the most sophisticated 2D and 3D weapon control and surveillance radar systems. This ability to create on command a simulation of a dynamic multiple-target/threat environment, including clutter and weather effects, allows for the performance of radar operator training to a degree previously unachievable. Instant recognition of and response to multiple threats is crucial to mission success and often to crew survival.

The key lies in the ability to simulate radar returns and jammer signatures with a degree of realism not differentiable from real world radar inputs. The equipment must provide in real time that portion of an electromagnetic environment comprised of multiple airborne targets, multiple chaff drops dispensed by the simulated targets, clutter, weather, and ECM waveforms emanating from selected simulated targets. The ECM waveforms should be capable of both denial and confusion techniques. In addition, the simulator must be coordinated with the real time operation of the radar with respect to radar pointing direction, range sweep timing, and transmitted frequency and phase. This modeling, therefore, should include accurate simulation of:

1. Signal strength variation due to target radar cross section (RCS) fluctuation.

2. Slant range and radar transmitter power.

3. Modulation due to target position in the antenna pattern (main, side, and back lobes.)

4. Doppler shift and doppler noise.

THE TECHNICAL PROBLEM

In order to create an illusion at the radar of actual radar returns, it is important to consider the many signal parameters and radar interfaces. These radar parameters shall first be briefly described and later followed by an in depth discussion into the dimensions of these parameters:

- Radar cross section
- Scintillation noise and other noise components
- Target dynamics
- Path loss factors
- Doppler
- Scan modulation and antenna gain
- Extended radar returns (chaff, rain, sea clutter)
- Jammers
- Radar (2D & 3D) and operator interface

Radar Cross Section (RCS)

The RCS model should be the result of a simple operator input of mean cross section over a range that considers all sizes of expected encountered targets.

Scintillation Noise and Other Noise Components

The model should include phase/amplitude fluctuation in regard to target aspect angle, amplitude noise modulation should simulate target cross section fluctuation, and Doppler frequency noise modulation.

Target Dynamics

The target model should be capable of simulating both maneuverable and fixed targets in three dimensions (range, azimuth, and elevation.) The maneuverable targets should be capable of linear and circular motion and of having a rate of ascent or descent applied individually.

Path Loss Factors

All losses that can effect return signal strength, whether one way or two way, should be modeled such as; signal attenuation as a function of target range, atmospheric attenuation as a function of radar frequency if above X band[1], rain attenuation, and chaff attenuation when extended over long ranges as in a corridor. These losses should be considered over a dynamic range and resolution compatible with expected target and jammer conditions.

Doppler

Target Doppler frequency should be modeled dynamically in accordance with the flight path motion of each target.

Scan Modulation and Antenna Gain

The absolute pointing direction of the antenna should be tracked in real time by the simulator. The antenna patterns should be used to provide coordinated amplitude modulation for all modeled signals with respect to the one way or two way antenna gain as required.

Extended Targets (Chaff, Rain, Sea Clutter)

Coherent radar returns from a number of extended targets, such as chaff, rain, and sea clutter should be modeled. The model should consider the additive effects of many scatterers, air mass motion effects, masking effects, and altitude, and in addition, should provide for both amplitude noise modulation to simulate cross section fluctuations and doppler frequency effects including doppler noise.

Jammers

The simulator should be capable of modeling a number of threats assignable to selected targets. Denial techniques such as barrage and spot noise and swept CW should be available. In addition, noncoherent types of confusion techniques such as range deception with a cover pulse, inverse gain, synchronous and nonsynchronous pulse train should be available. The coherent type confusion techniques should be range deception and inverse gain.

Radar Interface

The simulator model should be compatible with both 2D and 3D radars and a direct summation with the real world radar input.

Operator Interface

A simple operator interface is of paramount importance. Automatic and manual data entry should both be considered. In addition, a means of displaying continuously updated data on all targets should be considered.

A RADAR ELECTROMAGNETIC ENVIRONMENT MODEL

Radar Cross Section

Two distinct types of targets are considered, those that are short compared to a radar's pulse length and those that are long.

A target that is physically short effectively echoes a near exact replica of the transmitted signal. Radar echoes that are long include rain, sea clutter, and extended chaff drops. For long or extended signals, the radar return is no longer a simple replica of the transmitted signal, but a superposition of many, many returns from individual scattering centers. Extended target returns are discussed later in this report. The RCS assigned to each type of

target is based on measured mean values. For example, aircraft typically vary anywhere from 0.1 to a few hundred square meters.[2] This statistical mean is taken as a point of departure for all subsequent variation and is the operator entry into the system.

Scintillation Noise and Other Noise Components

The signal returned to the radar's antenna for any given target, even if physically very short, is known to vary from reply to reply. To achieve a realistic model, the more significant contributions must be considered.

The first important signal strength variation is the deviation from mean RCS due to irregularities of the target itself. Fig. 1 is a typical size aircraft. As can be seen, minor changes in aspect angle can vary reply signal strength up to 20 dB, yet for all of its wild variations, the return signal strength is essentially free of step functions.

When considering return signal strength variations on a pulse to pulse bases (PRI of 2 milliseconds) for an aircraft in a "g" limited maneuver the variations are quite minor. On the other hand, in the scan to scan period (perhaps 5 to 10 seconds) the return strength could vary 40 dB. We thus experience a high degree of correlation, pulse to pulse, and full decorrelation of signal strength scan to scan. The statistical behavior of the uncorrelated scan-to-scan fluctuation is well defined in literature as Swerling Case 1.[4] The probability-density function for the cross section σ is given by the exponential density function[4] (corresponding to a Rayleigh distribution of voltage.)

$$P(\sigma) \quad \frac{1}{\sigma \text{ av.}} \exp \frac{-\sigma}{\sigma \text{ av.}} \qquad \sigma > 0$$

The second most important signal strength variation arises from multipath.[5] Fig. 2 indicates the four possible multipaths considered on both transmit and receive.

Path one, the most direct one, has the least attenuation. Path two and three experience attenuation from a signal reflection but are both of the same length. Path four, the

longest of them all, experiences twice the bounce loss of two and three. The most

Experimental RCS Data
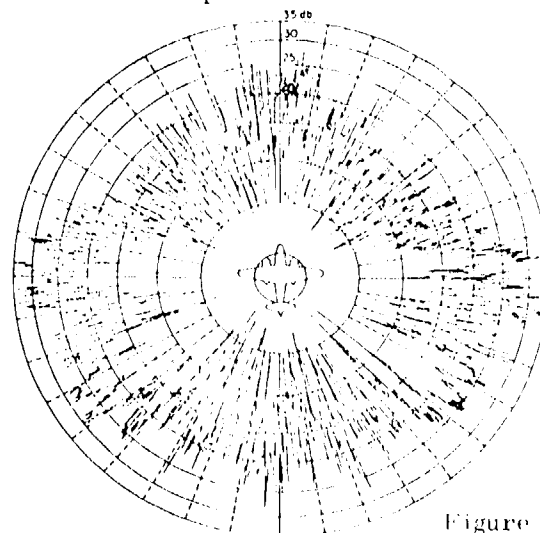
Figure 1

Experimental cross section of a two engine bomber at 10 cm wavelength as a function of azimuth angle.[3]

From MIT Rad Lab Series - Vol. 1
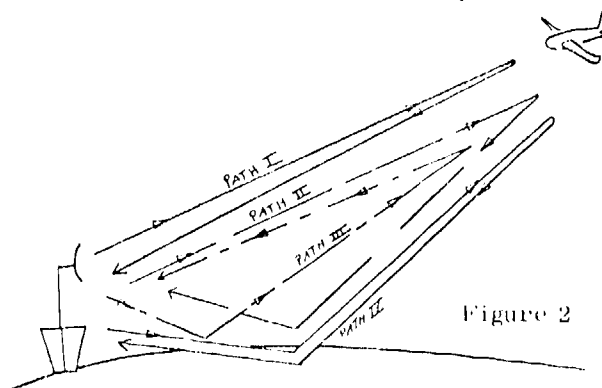
Figure 2

Multiple Signal Lines

significant signal is thus path one, of nearly equal significance the combination of two and three, and with a much lesser effect from path four.

This near equivalence of path one and the sum of two and three, were amply demonstrated by the naval tracking/tests run at Chesapeake Bay Annex during tracking experiments for low flying aircraft.

As signals in space add on a voltage basis, and as the two significant signals can be at any phase with equal probability, the

addition can vary from the norm of unity (say 1 volt) for the direct ray (path one) to a maximum of 2 Volts and a minimum of 0 Volts. Expressed in dB we expect a variation from 0 to +6 dB upward to infinity downward. The contribution from path four, however, prevents the zero (-infinity dB) and -10 dB is a realistic approximation.

The discussion above gave a basis for extent of the distributions used based on physical behavior. In addition, the beam pattern in the direction of reflection is simulated and used to control the reflected signal amplitude. A more detailed discussion of antenna pattern effects is contained later in this paper.

In literature Swerling I and II are often used as two distinct effects, some occuring at some time under some circumstances, and the other under some other conditions. Data recordings taken in the past on the AN/FPS-35, AN/TPS-36, and others have convinced us that a real life situation involves both effects, i.e. superposition of both a Swerling I and a Swerling II case.

Special provisions were made to insure that correlating data is correlated for replies from any one target, yet be decorrelated from another target, though within the same radar beam.

Since the variations of correlating data are time dependent, the degree of change is based on elapsed time only and the radar PRI does not enter the generation of correlated noise.

Target Dynamics

In order to create a dynamic scenario of multiple target/threat events a number of entered parameters must be acted on:

Target Number - Aircraft identifier

Initial Position - Range, altitude, elevation

Radar Cross Section - Mean cross section in meters ^{2}

Target Dynamics - Heading, velocity, turn rate (right or left,) elevation rate (ascent or descent)

Designated Jammer - COHO/NCOHO type, ERP, pulse characteristics, target number, frequency.

Designated Chaff Dispenser - Type, mean cross section, extent, target number.

To properly output the target data into the receiver front end, time and phase coherent with all radar system aspects requires a number of events to take place. The target model must perform the following functions during each radar PRI, properly synchronized with the transmitted signal and the radar antenna pointing direction, considering both target azimuth and elevation:

- Automatically acquire radar transmitted pulse characteristics

- Acquire radar transmitter frequency and coding

- Acquire transmitter peak power level

- Determine time delay for target range

- Determine target bearing in relation to antenna azimuth angle

- Determine target altitude in relation to antenna elevation angle

- Correlate target position with any interposed environmental model

- Calculate doppler offset frequency as a function of slant range rate

- Output pulse frequency phase coherent with radar transmitter including any doppler offset

- Calculate "target power" as a function of target RCS and radar transmitter peak power

- Determine antenna gain as a function of target position and antenna pointing angle

- Determine one way (jammer) or two way (skin return) path loss as a function of slant range

- Determine atmospheric attenuation as a function of frequency and range if applicable

- Determine rain attenuation if applicable

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- Output target pulse in real time synchronism at the proper power level and frequency

The above model parameters are applicable to each target inputted into a scenario. As the number of targets and/or events increase, additional determinations enter the generated model.

The multiple targets must be properly range ordered and azimuth and elevation gated in synchronism with the radar. Each PRI targets must be updated in range, azimuth, and elevation to be properly outputted into the radar receiver at a rate and resolution in excess of radars discriminating capability.

Path Loss Factors

The radar range equation[7] readily calculates the signal strength a radar receiver would see given some of the basic parameters of the radar's operation (frequency, power) and the location (range) of the target.

$$P_r = \frac{Po\ G^2\ \sigma\ e^{-2\,aR}\ \lambda^2}{(4\,\pi)^3\ R^4\ L}$$

The radar range equation in the form shown above makes a number of assumptions, one of which being that there is but one path between the radar and the target. In addition, as has been discussed previously the RCS is a variable, together with attenuation and radar system losses. The simulation must take into account these variations to present a realistic model.

The RCS variations have been previously discussed together with the multipath considerations between radar and target. Added to the model are two other attenuation factors in addition to the return signal attenuation as a function of range. These are atmospheric losses as a function of frequency and range[8] if applicable, and the attenuation of signal strength when in or behind rain[9].

Doppler

All moving targets generate a Doppler offset frequency proportional to their slant range rate.

These targets are not only the maneuverable targets, but also the extended targets such as chaff, rain, and sea clutter.

The Doppler effect[10] causes the signal reflected by a moving target to be offset in frequency by an amount $f_D = 2V/\lambda$ where f_D = Doppler offset frequency (Hz) V = relative velocity (slant range rate) between radar and target (m/sec.) λ = Wavelength of carrier frequency (m).

In order to properly output each moving target pulse, phase coherent with the radar, the proper Doppler offset frequency must be modeled. This will require two simulator calculations. One, to determine the instantaneous slant range rate as a function of the present target velocity and heading, and second, calculating the Doppler offset frequency or phase.

An understanding of how a radar processes the incoming signals to differentiate between nonmoving clutter and moving targets helped to arrive at the solution implemented.

On a short pulse basis common to most radar systems, it is an impossibility to determine the phase change, as a result of Doppler offset. However, an examination of successive PRI's shows that echoes from fixed targets remain constant throughout, but echoes from moving targets vary in amplitude from sweep to sweep at a rate corresponding to the Doppler frequency.

Figure 3 illustrates this phenomena. (Taken from Skolnik "Introduction to Radar System") pg. 116.

By measuring or detecting this phase change on successive PRI's a determination can be made of the presence of moving targets.

Two different models can be used in the simulation of Doppler. Precision offset oscillators yield excellent duplication of Doppler with good spectral purity. Since, however, one oscillator must be dedicated to one speed, the range of speed that can be simulated is limited. An alternate approach is the use of phase shifters, with some digital networks dedicated to each target in view. Since the
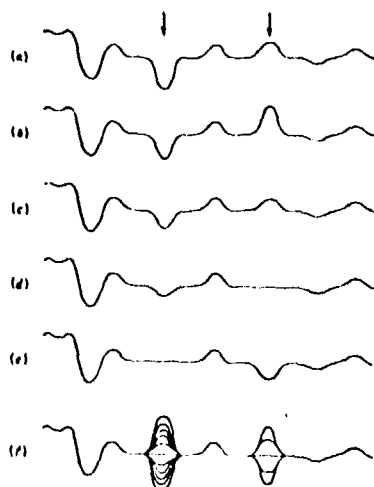
Moving Target Returns

Fig. 3 (a -e) Successive sweeps on an MTI
radar A-scope display (echo amplitude as a
function of time); (f) super-position of many
sweeps; arrows indicate position of moving
targets.

phase is constant during each transmission
period, the spectral purity is not quite as
good as the individual oscillator, but this
approach can readily handle a multiple of
speeds and targets. Typically a 4 bit phase
shifter in an L band system yields a speed
resolution of about ± 10 knots for a simulated
target speed from 0 to $\pm 2,800$ knots, i.e.
$\pm 1/4\%$.

Extended targets in this simulation model
are considered stationary in range and azi-
muth, have a vertical fall velocity, but with-
out air mass motion. Turbulence is imple-
mented with a statistical noise model and
wind shear effects are not considered. By a
correct choice of AM noise modulation band-
width, the sought for Doppler spread (sym-
metrical about zero) is duplicated by the AM
sidebands of the AM modulating signals. The
rise and fall times of the generated AM noise
signals previously discussed, can be control-
led to yield the spectral spread and thus the
range of the simulated Doppler spread.

Scan Modulation and Antenna Gain

To continue on the approach of creating
as realistic a model possible, actual antenna
pattern data experimentally obtained can be
utilized to amplitude modulated the simulated
targets. The model created considers the

effect of gain, side lobe structure, and half
power beamwidth. The approach considered
is to store the values of antenna gain relative
to peak in ROM with sufficient capacity de-
pendent upon the desired resolution and sys-
tem accuracy. The ROM address locations
are then determined by the angle away from
boresight. By this technique there is no
restriction on antenna pattern symmetry.
The only restriction is based on storage
capacity and the bits allocated for ROM ad-
dressing. For the usual target return loss
the antenna gain is used both in the transmit
link and the receive link. For most jammer
cases, it is only needed for the receive cal-
culation.

Extended Targets (Chaff, Rain, Sea Clutter)

Extended targets create an echo return
that is no longer a simple replica of the
transmitted signal; but a superposition of
many returns from individual scattering cen-
ters.

Extended or long targets require some-
what different techniques to simulate. For
one, these targets do present a shape of their
own which has to be superimposed with the
radars own parameters.

In range, the convolution is that of the
radar pulse, a square wave, with that of the
extended target shape, such as rain or chaff.
Similarly, a convolution integral is used to
determine the combined effects of target and
antenna pattern azimuthal variations.

For chaff, the variations are two fold.
The vertical variations with time can best be
described as a normal distribution with the
upper 2-sigma anchored at the level of sowing
and a mean fall rate dependent on the material
employed. Typically the centroid fall rate is
about 250 ft/minute. [11] Simultaneously the
lateral spread, perpendicular to the direction
of sow increases at about the same rate.

Rain, though similar to chaff, in certain
respects has some significant differences.
For one, once rain has initiated, with its
higher fall velocity, it can be taken as (a)
reaching the ground in near zero time, and
(b) having a vertical profile uniform from the
ground up to the level of the forming cloud.

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Also, while chaff has some kind of uniformity along the line of sow, rain is a more central phenomenon. It contains a near circular center with a density taper toward the edges. Again, unlike chaff, while the reflectivity decreases outward from the center, it does not taper to zero but experiences a step function near its edges providing a definite profile.

Further, in the consideration of Doppler, the majority of the rain motion is vertical, and any lateral motion due to wind is uniform to all rain drops. The last statement holds for the rain below the cloud, which is the majority of the rain field in radar view, though not within the storm center of the raincloud. While it is true that rain within the center of the cloud, the region of turbulence, experiences large radial motion (up to 6m/sec[12] versus 1m/sec for chaff[13],) the model simulates the free fall rain region. Since the rain within the center of the cloud subtends but a small vertical angle, it can be neglected for search radar simulation.

In the discussion of the small targets, the multipath problem was considered (i. e. the superposition of two different signals (Path I and Path II and Path III)). In the case of large extended targets a similar effect takes place, however, with many many more reflectors delivering their one reply at slightly different times and phases. For small targets, the effect was a variation of the amplitude of the total simulated signal and a finer resolution is not necessary, since the receiver bandwidth is matched to the transmitted signal duration. For extended targets, however, the receiver can resolve such variations though bandlimited to the signal bandwidth. Thus the random variations, as discussed previously under multipath, of +6 to -20 dB are again superimposed on the return signal. A noise pattern is generated with the data varied in a broadband manner with frequencies compatible with the receiver bandwidth. This high frequency noise (500 KHz for a 2 microsecond radar) is then superimposed in the amplitude patterns representing the convolution of the target physical reflectivity profile and the scanning antenna pattern.

For simple pulse radars, the chaff/rain signal model is complete at this point. For chirp systems one factor has to be considered, in that scatterers at different ranges reply

with different frequencies at the same time. For small targets a replication of the FM pulse suffices. For extended targets an additional high rate FM modulation is required to simulate the receipt of multiple frequencies at the same time while maintaining the pulse to pulse frequency reference. For the simulation of extended targets, the modulating wave shape is modified to simulate the frequency centroid as a function of time during the return signals duration (pulsewidth, plus target depth.) The new centroid waveshape is further modulated with a high frequency signal (higher than the receiver bandwidth,) whose peak to peak excursions correspond to the earliest and latest frequency in view at any given instant.

The sea return signal uses similar techniques. If differs from either the chaff or the rain (longitudinal or cylindrical symmetry) in its density pattern.

While rain or chaff are isolated phenomena, sea clutter differs in that (a) it surrounds the radar (360[0]), and (b) it appears only at close in ranges, less than 15 NM from the ship's radar horizon for low antenna grazing angles.

In accordance with Skolnik[16] "it seems to have been well established that theories describing radar scattering from the ocean must take account of the small-wave structure (ripples, capillaries, facets) as well as the large wave structure." Kaltzin[16] facet theory, supported by measurements taken by Schooley, appears to present the best model. He advanced the suggestion that, instead of droplets, the scattering elements are small patches, or facets, that overlie the main large-scale wave pattern.

The main reflecting patterns are known to be correlated to the wind direction (not wave direction) and appear as slowly moving reflecting strips perpendicular to the wind direction. Additionally, minor small targets appear to fill in the spaces between the main scatterers, though of less scattering crossection.

There is one more wind caused effect, in that the mean reflections are maximum into the wind, somewhat less alee, with an even further reduction cross wind yielding an hourglass figure for the clutter simulation.

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The complexity in forming a sea state pattern is in the generation of the cross wind lines and minor scatterers as a function of wind direction; which in general, correlate on a scan to scan basis but drift in general position as a function of minutes. The simulation of the multiscatter effects are handled similar to other extended targets.

Jammers

To complete the electromagnetic environment model, consideration must be given to expected threats. As a result, provision has been made to include simultaneous coherent and noncoherent radiation from collocated jammers. The replication of these jammer platforms is accomplished with independent ERP control and various operation modes. Among these are coherent range deceptions (including cover pulse) and inverse gain, noncoherent swept CW, spot and barrage noise, plus synchronous, and nonsynchronous pulses.

Radar Interface

In order to achieve the degree of coherency necessary, certain information is required from the radar. The STALO and COHO frequencies are necessary to recreate a return echo with the necessary degree of phase coherency. A main bang trigger to synchronize the system and antenna scan and platform information are also necessary. Fig. 4 indicates the major interfaces.

Operator Interface

To simplify use of the system, a microprocessor controlled video display terminal was selected out of the many considered. Data may be entered by means of the keyboard, RS-232 serial or IEEE STD 475 paralled data link inputs. The operator provides the simulator with information relating to the aircraft and the radar. This information includes the aircraft identification, signature, and motion dynamics. Also entered are the radar parameters including frequency, amplitude, and time dimension.

The parameters defining the nature of the chaff and the type of jamming is entered for each aircraft that carries these countermeasure capabilities.

The data that has been entered for the

aircraft, radar, chaff, and jammer is presented on the display. As the data changes, the display changes. There is a constant updating of the aircraft position to show its new range and bearing at any time during the mission. Automatic self test and a predetermined scenario may be initiated at any time by operator or data link intervention.

REES Concept
Figure 4

REES CONCEPT
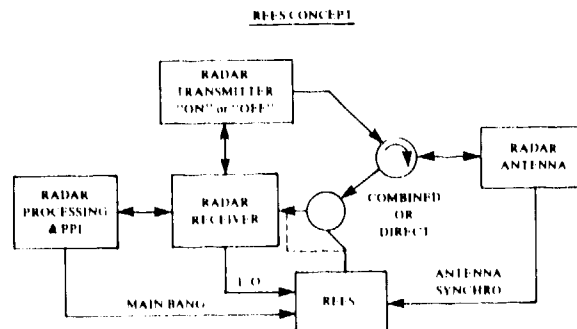
MODEL IMPLEMENTATION

Hardware Implementation/Radar Interconnect/Control

A simulator incorporating many of the features discussed in the previous section was designed, fabricated, tested, and delivered. It was designated as a Multiple Threat Generator (MTG-100) and was integrated at the Signal Processing Laboratory Radar at Rome Air Development Center (RADC.) Its performance characteristics are included at the end of this section.

Figure 4 shows the simulator and its radar interconnections and Figure 5 is a simplified block diagram of the simulator with its interconnections. A more detailed block diagram depicting a single channel of the MTG-100 is shown in Figure 6. One such channel is available for each R. F. band the simulator is to be operated in.

Each channel consists of two chains, a coherent and a noncoherent chain. The input frequency of the coherent chain is determined by a signal derived from the radar local oscillator.

In the system chosen as illustration, the radar transmitted frequency is 80 MHz above

the local oscillator input. The 80 MHz os-
cillators are crystal controlled VCO's, one
dedicated for each target, allowing Doppler
shift simulation to be achieved by offsetting
the XVCO's.

The mixed product is amplified to compen-
sate for mixer conversion loss and component
insertion losses.

A series of control elements (i.e. linear
attenuator, R.F. switch, digital attenuator)
are used to control the amplitude of the R.F.
signal. The 30 dB linear attenuator super-
imposes the noise modulation generated by
digital noise circuits.

The R.F. switches are   sed to pulse mod-
ulate the signal (with pulse vidths as narrow
as 100 nanoseconds to full   W) with an on-off
ratio of 120 dB.

The actual control of the R.F. circuitry
is the responsibility of the digital interface
circuitry under the control of a micropro-
cessor. The microprocessor performs the
calculations for the proper attenuator word,
computes the range delay, and sets the pulse-
width. In addition, there is circuitry for
azimuth gating based on radar antenna pos-
ition and beam width.

The digital attenuator (.1dB steps to 120
dB) is driven by the CPU and digital inter-
face circuitry to provide the range, antenna
pattern loss and other dynamic and static
losses.

Figure 5
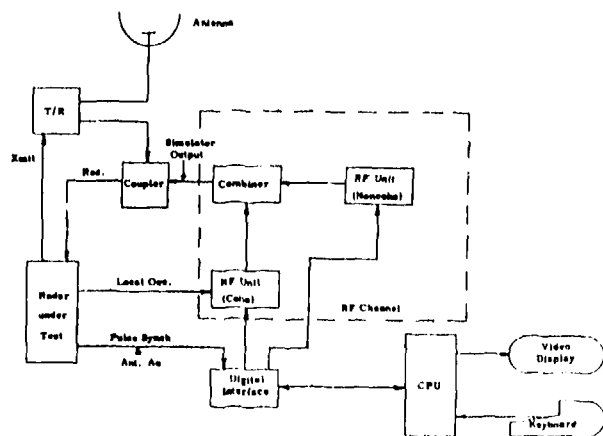
Radar Simul tor R. F.

Block Diagram   Figure 6
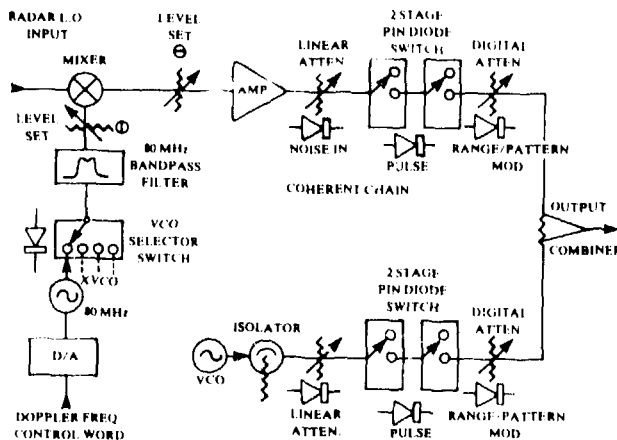
Both the coherent and noncoherent sig-
nals are combined at the output and are avail-
able at a single output port.

The R.F. coherent signal is combined
with a signal generated by a voltage controlled
phase lock loop oscillator whose output fre-
quency is digitally selected. This second os-
cillator is the R.F. source for the noncoherent
chain which provides simultaneous jammer
signal capability.

The digital circuitry, Fig. 7 consists of
three main elements: a video terminal, the
central processing unit, and the interface
hardware circuitry. The video terminal is
essentially the front panel of the radar simu-
lator. This terminal may be used to enter
all data, control commands and make scenario
decisions. The operator obtains current
status and other housekeeping information
from the display.

Software Implementation

Both dynamic real time and static pro-
cessing is achieved with the assistance of
two 8080 microprocessors with both indepen-
dent RAM and common memory. The micro-
processors perform the radar power and
cross section calculations, as well as range
ordering and bearing positioning. The com-
puters also provide the routing of data in and
out of the video terminal for both display and
operator interactivity.

Updating of the scenario and formatting
of video data is performed by the CPU's.

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The mainline program is stored in less than 8K of PROM. The CPU's perform a range ordering task and provide a "shadow" signal whenever two targets are within 10 µs of each other. The range ordering which at present is a modified "bubble sort," arranges the aircraft in the order of radar response at their computed ranges. This order, which is strictly range dependent, is then gated with the antenna azimuthal information. Each time the azimuth gate (representing the antenna beam painting of a particular angular sector) repeats a particular sector, the order of the range of targets could possibly be different. A comparison is made between each target, its radial range component is considered, and all of the targets are repositioned.

The data transmitted to the interface hardware consists of static data, computed once each time data is entered from the terminal, and dynamic data, computed during the scenario update about once each 5 millisecond interval. Range and range related phenomena is computed on a 50 foot resolution interval and Doppler frequency from 0 to ±2,100 knots in 1 knot increments.

Digital System Block Diagram

Figure 7

In order not to disturb the simulation when new data is available from the CPU's, two data registers (Readout Files) are used in the interface hardware. Data is read in and changed in one, while read out on the other file. By this "ping-pong" approach, a smooth update is maintained and synchronization between the radar main band and the CPU clock is not needed.

Noise Modeling

The noise seen by a radar when receiving a skin return is comprised of several elements which are both time dependent and target dependent. One element of noise is a result of angular displacement (GLINT.)

There is another element that is spatial contribution which is related to antenna position, target cross section and target orientation. A further distinction has to be made between noise from aircraft returns and that from chaff returns.

For a single aircraft the amplitude modulation, whose probability density function is a chi-square distribution, decorrelates both with time and frequency. It also provides scan to scan independence. This component of noise as instrumented represents the GLINT portion of the noise modulation.

The second element of the noise modulation is the contribution due to target fading. This fade pattern is a slow change in target return amplitude due to aspect angle changes. This spatial component was instrumented using a cosine ^{4} function with a variation in the period as a function of the target. The "Fade" component, therefore, was empirically derived and assures different noise behavior for different targets.

The amplitude range of the total aircraft noise is limited to 30 dB with the mean at 6 dB. The chaff noise modulation has a 10 dB variation (±5 dB).

In the case of chaff, a time invariant antenna position component must be generated. This models the expected variation in noise as the antenna sweeps different portions of the chaff. The noise will be highly correlated for angular changes which are small compared to the half power beamwidth of the antenna and completely decorrelated when the antenna moves greater than the half power beamwidth.

Noise Jammer

While the coherent noise distribution is determined by the data stored in the various ROM's dedicated for this task, it is also necessary to generate noise to be used as modulation for on-board jammers. (The airplane is the jammer platform.) This is done in an analog circuit using a noise diode and amplifier as source voltage for a linear attenuator. This modulator affects the noncoherent signal (representing jammers) only. For broad band (bar-

rage) noise, it was necessary to use a somewhat different approach than amplitude modulation. The linear modulator's modulation bandwidth is only about 300 KHz. Barrage noise should produce a spectral bandwidth in excess of 20 MHz. To accomplish this, the same noise diode source is used, amplified, and superimposed on the error voltage of the VCO. The phase lock circuit cannot respond fast enough to correct this noise voltage and the result is a noise modulated FM signal. This signal occupies a bandwidth of better than 20 MHz and spectrally simulates a barrage jammer.

Antenna Pattern Generation

The MTG-100 system is capable of modeling the effect of gain, side lobe structure, and half power beamwidth of an actual or ideal antenna pattern. The values of antenna gain relative to the peak are stored in 1024 locations where the address location is determined by the angle away from boresight. There is no restriction on the antenna pattern symmetry.

For the usual radar target return loss, the antenna gain is used both in the transmit link and the receive link. For the jammer case, it is only needed for the receive calculation. Therefore, only the "one way" gain of the antenna is stored in the ROM's and the interface circuitry doubles the gain in the "two way" case.

Doppler

Regardless of the Doppler processing techniques of the radar under test, the Doppler shift associated with a particular target must maintain its offset frequency and phase continuity. Because the radar only sees the target for a small portion of the Doppler cycle, it must take several samples and reconstruct the Doppler shift.

At present, the Serrodyne method or the single sideband method at best would produce spurious frequencies and carrier leak-through that would be between 20 and 35 dB below the carrier. To assure that spurious outputs specified are 50 to 55 dB below the desired output, a separate oscillator was used for each target. Each of the oscillators are continuously operating and are assigned to individual targets. The outputs are selected under CPU control when that target is to appear. The selector switch presents a load to the oscillator at all times, thereby eliminating possible pulling during switching.

The CPU was used to calculate the Doppler shift needed based on operator inputs of velocity and radar frequency used. The calculated Doppler shift word was applied to a digital analog converter whose reference voltage provided the scaling factor to convert the frequency word to a correct shift of the XVCO frequency.

The simulation of chaff Doppler presents a different challenge. The chaff cloud requires a random shift correlated with time and operating frequency. The signal produced for amplitude modulation of the chaff noise has a component which is related to both time and frequency. By using this component before it is combined with the spatial noise component, the chaff Doppler was derived both as a function of operating frequency and time. This simulates the effect of wind shear, dipole tumbling, turbulence, and falling of the chaff cloud.

Equipment Installation

The equipment was successfully installed at RADC with the radar interface accomplished via a 20 dB directional coupler to minimize any degradation of radar receiver sensitivity. Test data was obtained and the MTG-100 met the performance characteristics specified in the contractual statement of work and listed in Table 2.

Problems Encountered

One of the major problems encountered during the design phase of the MTG-100 was in the generation of the Doppler offset frequencies. The initial concept utilized a phase locked VCO switched in frequency to generate each Doppler offset frequency to be mixed with the incoming radar L.O. frequency. This concept basically ignored the degree of phase coherency and memory required to be dedicated to each moving target, PRI to PRI, within the antenna beam, and the requirement that carrier leak through be 60 dB below the Doppler offset frequency.

Performance Specifications   Table 2

	Baseline	Options
Frequency	1250 - 1350 MHz 2900 - 3700 MHz (1 MHz steps)	0.5 to 18 GHz
Output Power:	Coherent Channel -6 dBm Noncoherent Channel 0 dBm	
Dynamic Range:	100 dB (0.1 dB steps)	
Doppler Simulation	0 to ±2100 knots	
Target Capability:	6 Aircraft, 9 Chaff Events (Point, Medium, Large)	127 Aircraft plus Chaff Events
Chaff Motion & Effects	Stationary	Air Mass Motion, Screening, Altitude
Environmental Anomalies		Sea Clutter, Rain, etc

Target RCS Range	0.1 to 1000 meters²	
RCS Dynamics	Static Mean plus Scintillation	Dynamic Tracking
Target Pulse Width	0.1 to 90 microseconds	
Target Range	1 to 400 NM	
Target Azimuth	0 to 360°	
Azimuth Rate	±6 degrees/second	
Radar/Jammer Power	0 to 100 dBW	
Jammer Simulation Number	2	Heavy Density Model
Type	Coherent & Noncoherent	
Modes	Range Deception (including Cover Pulse), Inverse Gain, Synchronous & Nonsynchronous Pulses, Swept CW, Spot Noise, Barrage Noise	
Antenna Pattern Data	Azimuth Coverage (22.5°)	Azimuth (360°) Elevation
Complex Waveforms		Pseudorandom Binary Phase Coding 200 Megabit/Sec Rate
Identification		IFF

RADAR OPERATOR/MAINTENANCE TECHNICIAN TRAINING

If a situation can exist, that requires judgment and operator skills to properly evaluate and respond to, that situation needs to be repeatably generated for proper training. If a judgment may be necessary dependent upon various shadings of displayed data, proper training can only be accomplished by either generating the actual conditions (flight/jammer trials) or by having available a realistic simulation.

Both of the above training aspects can be cost effectively realized by the use of a properly specified electromagnetic environment simulation. By properly specified, we mean an environment simulation virtually undifferentiable from the real world. Add to this a capability to generate a dynamic multiple-target/threat environment with chaff dispensing aircraft, sea clutter, and rain events, and the ability to sum these signals with real world inputs, all sorts. of training scenarios become possible.

CONCLUSIONS

To achieve a high degree of operator competance in interpreting a radar display in a threat environment requires a high degree of signal realism. The target/signal models used in the simulator discussed were based actually upon data obtained, under a variety of conditions, using various radar systems. Today's electronic technology allows the generation of a simulated radar electromagnetic environment virtually undifferentiable from real world returns.

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AN ADVANCED REAL-TIME TRACKING SYSTEM
FOR EW TRAINING

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INTRODUCTION

The Advanced RMS is an improved version of the RMS/SCORE (Range Measurement System/Simulated Combat Operations Range Equipment). It combines the best features of the RMS family of tracking systems and the EATS/CTS technology. The RMS family of precision range tracking systems, produced by General Dynamics Electronics Division in San Diego, consists of discrete address, interrogate-respond, multilateration position location, and digital data communications systems. The RMS systems provide the capability for tracking numerous participants in real time, and for sending and receiving data to and from these participants.

The results are displayed for both real-time monitoring and control, and post-exercise critique and evaluation. The Extended Area Tracking System (EATS) recently installed at Pt. Mugu NAS and the Pacific Missile Range, and its successor the Cooperative Tracking System (CTS) for the Mobile Sea Range are also produced by GDE. These Navy systems employ spread spectrum and pulse position modulation along with other features representative of modern technology. The Advanced RMS incorporates spread spectrum and pulse position modulation features, and includes other improvements to significantly enhance the anti-jam capability of the system and improve its data handling capacity.

This paper reviews certain of the applications and architecture of the RMS and RMS/SCORE systems, then describes the features of the Advanced RMS and its application to realistic EW test and training.

BACKGROUND

The initial development in the evolution of the Advanced RMS was the delivery in 1969 of the RMS-2 system to Fort Hunter-Liggett, California. This system has been used by the U.S. Army Combat Developments Experimentation Command for tactics development and weapon system testing since then. Numerous enhancements have been made to the system over the past decade, including the capability to interface with a laser weapon simulator system to allow Real-Time Casualty Assessment (RTCA).

In 1971, DDR&E ordered the production of an RMS-2 system to support the Combat Hunter Phase III OT&E testing. That system provided the tracking data for four Maverick-equipped F-4 aircraft against threat armor, which was also tracked. F-4 Maverick events (slew, lock, and launch) and ground fire events were collected by the system. It has been used to provide position location and data communications in numerous joint tests since then. It has been continually extended and upgraded and has acquired the acronym RMS/SCORE.

Many of the tests supported by the RMS/SCORE system included various aspects of electromagnetic combat. These include:

Electronics Warfare Joint Test, Phase I, 1973. Conducted at China Lake, California, the system was used to track up to six aircraft conducting simulated strikes against a typical SAM-defended site. The tracking data was used to access the effectiveness of the EW equipment in the strike aircraft.

Electronics Warfare Joint Test, Phase II, 1974. On the Nellis North Range, the system provided aircraft tracking data for up to 16 aircraft conducting simultaneous simulated strikes over a 60-nmi by 80-nmi area. In addition, simulated AAA sites were instrumented on the ground. Data collected in this test were used to evaluate the effectiveness of airborne EW hardware and tactics against current threat air defenses.

Imaging/Infrared Maverick Test, 1977. Elements of the RMS/SCORE were used to collect data from F-4 aircraft using the new Imaging/Infrared Maverick against ground threats.

Tactical Aircraft Survivability Evaluation, TASVAL 1968-79. This series of test was conducted at Fort Hunter-Liggett where the assets of the RMS/SCORE and the CDEC RMS-2 were combined. This test was designed to determine the survivability of various tactical aircraft, especially A-10's and AH-1's, in simulated close air support strikes against threat armor. All participants were equipped with laser gun simulations that generated pairing and hit/miss data which was collected by the RMS data link. Both air-to-ground and ground-to-air weapons simulations were performed to evaluate the test objectives. Tactical aircraft were equipped with RMS/SCORE pods to provide full position, velocity, acceleration and attitude data for the simulations. An example of the variety of participants tracked in TASVAL is shown in Figure 1.

QTY	PLAYER	FILTER STATE	POLLING RATE	RANGE SETS PER SECOND
1	Airborne Interrogator	(9 State)	5/sec.	5
4	AIS Pods	(10 State)	5/sec.	20
8	ARPIS Pods	N/A	5/sec.	40
9	Helicopters	(6 State)	2/sec.	18
86	Ground Participants	(3 State)	.25/sec.	21
3	ZSU	(3 State)	1/sec.	3
4	I-Hawks (Fixed)	N/A	1/sec.	1
				108

Figure 1. RMS Tracked and Collected Data From 115 Participants for TASVAL

Electronics Warfare During Close Air Support, EW/CAS 1980-81. The RMS/SCORE system was recently deployed to the Nellis North Range where it provided tracking and pairing data in support of the EW/CAS joint tests. In this application, 27 ground threat sites and up to 28 airborne participants were equipped with RMS transponders for tracking and data collection. The role of the RMS and application of the Advanced RMS in this type of exercise is described later in this paper.

In addition to the RMS-2 at Hunter-Liggett and the mobile RMS/SCORE, GDE has delivered four additional systems to the Army and Air Force which are fully compatible in both operational application and hardware. Two more systems are presently under contract for delivery later this year and next year. Although all of the RMS family of systems are completely interoperable, they are known by various acronyms. Table 1 shows the RMS systems presently operating or under contract.

Table 1. RMS/SCORE Family of Systems

NAME	LOCATION	DATE DEPLOYED	OWNER
RMS-2	Ft. Hunter-Liggett, CA	1969	U.S. Army/CDEC
RMS/SCORE	Various DDR&E Joint Test Sites	1972	DDR&E
PLS/DCS	Yuma Proving Ground, AZ	1975	U.S. Army/TECOM
HAMCTS	Utah Test Range, UT	1976	USAF/AFFTC
RMS-2	Nellis North Range, NV	1978	USAF/TFWC
MTTS	Ft. Bliss, TX	1979	U.S. Army/ADB

SYSTEM DESCRIPTION

The Advanced RMS system consists of four major subsystems, illustrated in Figure 2. These subsystems are functionally identical to their counterparts in the RMS/SCORE and other RMS tracking systems. The Tracking and Communication Subsystem (TCS) collects range measurements and
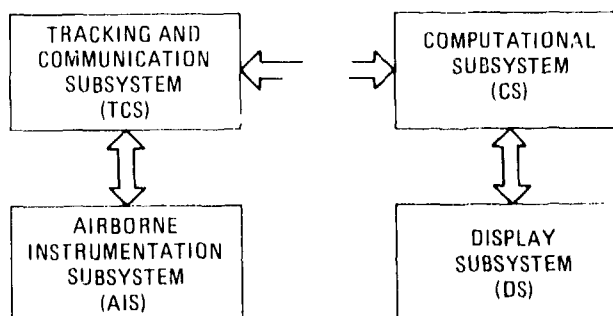

Figure 2. The Advanced RMS Consists of Four Integrated Subsystems

digital data from transponder-equipped participants. This data is sent by hardwire or microwave to the Computational Subsystem (CS) for processing. Participant parameters, weapon simulation results, and scoring data computed in the CS are then sent to the Display Subsystem (DS) for real-time display and control. All the data is recorded for post-exercise debriefing and evaluation. The fourth subsystem, the Airborne Instrumentation Subsystem (AIS) is a fully instrumented pod which provides aircraft attitude, air data, weapons data and other parameters as required.

Tracking and Communications Subsystem (TCS)

The Tracking and Communications Subsystem (TCS) is the key to the flexible and expandable capability offered by the Advanced RMS. Its functions are to collect ranges and digital data from the participants and to transmit digital data to the participants through the transponder. There are three basic elements of the TCS:

1. A computer-controlled Central Station, which can be manned or remote.

2. Remote Interrogator/Relay Stations, called IRR stations.

3. A microprocessor-controlled transponder.

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The heart of the TCS, and indeed of the Advanced RMS, is the transponder, which operates under microprocessor control to function as a reporter, a responder, or a relay. In the reporter mode, the unit interrogates responder units in order to measure inter-unit range and transmits that data to the Central Station. In the responder mode, the units respond to a reporter interrogation with a range pulse and other data as requested. In the relay mode, the units transfer out-bound or in-bound messages as dictated by line-of-sight or distance considerations.

Since the transponder performs all the required functions of interrogation, response, and relay, different electronics packages at the IRR sites are not required. The electronics units at all sites including the Central Station are functionally and electrically identical.

The interrogator/relay stations are unattended sites generally powered by solar panel/battery systems. If other power is available, i.e., commercial or generator power, that source can be used. The interrogator/relay stations consist of a tower, various antennas, the solar cell power supply, and the electronics unit. Figure 3 is an illustration of a current RMS A-Station. The IRR station would be identical, with the only change being the electronics housed in the suitcase-sized enclosure.
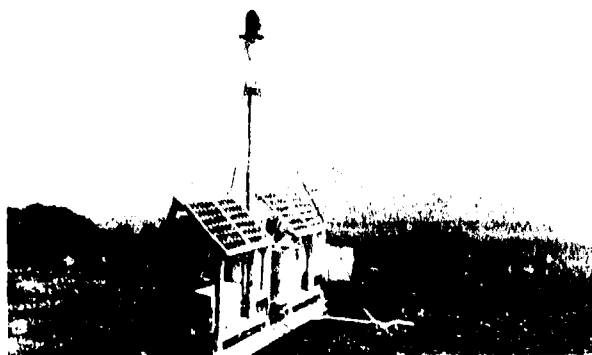

Figure 3. Typical Site Installation

The Central Station consists of a minicomputer, the RF electronics and logic circuits, and a time-code receiver and generator. It can be housed in an unmanned shelter and controlled remotely from the Computational Subsystem (CS) or in a manned facility. The minicomputer functions to schedule and control the collection of range and digital data, time-tag and format data sent to the CS, and schedule data uplinked to the field units. In the manned configuration, limited real-time data processing and recording can be accomplished, providing a stand-alone capability for the TCS.

The RF electronics of the Central Station are functionally and electrically identical to the transponder, and can perform in any of the modes,

although the relay mode is not applicable to the Central Station.

Computational Subsystem

The Computational Subsystem (CS) receives time-tagged range and digital data from the TCS. The primary function of the CS is to compute position, velocity and acceleration data based on range measurements made by the TCS. If the participant is equipped with an Airborne Instrumentation Subsystem (AIS), aircraft attitude is also computed. In addition, the CS receives all digital data messages, processes them as required, performs weapon simulations and computes hit/miss and P_k data, generates uplink messages, and provides data to the Display Subsystem for real-time display and recording for post-exercise debriefing and analysis.

Kalman filters form the heart of the estimating and prediction computation in the CS. GDE has implemented various filters ranging from a simple 3-state position tracking filter to a 15-state filter which tracks the errors in the states of the aircraft, including the gyro drift and the accelerometer bias in the AIS inertial sensor assembly. The CS can also perform various air-to-air, air-to-ground and ground-to-air weapons simulations. These simulations are activated by firing signals received from the participant through the TCS digital data capability. The simulation can take into account target motion during weapon time-of-flight and score the results for display purposes or recording.

Display Subsystem

The Display Subsystem serves as the real-time Mission Command and Control Center for test or training exercises. Like the CS, the DS can be housed in a building or a 3 by 5 meter van as shown in Figure 4. Processed data from the CS is received by the DS minicomputer and displayed in various formats as required by the display operations or exercise controllers.

Figure 4. Typical Van-Mounted Display Subsystem

The DS contains direct-view CRT and large screen displays for audience viewing. Displays are presented in both 3-dimensional graphic views and 2-dimensional graphic or alpha-numeric displays. The 3-D graphic allows rotation and translation in all axes and variable scale for zoom capability.

The display consoles also contain remote intercom, VHF, and UHF controls to allow communications between system operators/evaluators and participants. Both real-time digital data and voice communications are recorded to permit complete playback for post-exercise debriefing and analysis.

Airborne Instrumentation Subsystem (AIS)

The Airborne Instrumentation Subsystem is used when full-state vector tracking of an aircraft is required. The AIS pod is compatible with AIM-9 Sidewinder aircraft mounting, umbilicals, and handling equipment. The pod contains:

1. A strapdown inertial sensor assembly (ISA).

2. A digital interface unit/digital processor unit (DIU/DPU).

3. A pitot tube and air data unit.

4. Antenna and power supply.

5. Provisions for a radar altimeter and associated antennas.

The transponder is also contained within the AIS pod, but is functionally an element of the Tracking and Communications Subsystem.

In addition to the position, velocity and acceleration computed by the system without the pod, the AIS provides aircraft attitude and other data such as sideslip and angle of attack, and aircraft weapons bus data. In the case of aircraft equipped with the 1553 serial data bus, virtually any aircraft parameter can be picked off the bus, and linked through the TCS to the Display Subsystem.

The AIS is used in a closed-loop computational configuration with the CS. The DIU/DPU in the AIS computes the aircraft state vector in tangent plane coordinates and transmits this data to the CS via the TCS. In the CS, the errors in the aircraft states and ISA are estimated in a 15-state Kalman Filter. Ranges collected by the TCS are used in the measurement equation to determine corrections to be transmitted to the AIS. In the pod, these corrections are incorporated and the data base adjusted before the next set of state values is sent to the ground.

Advanced RMS Design

Throughout the history of the RMS family of tracking systems, numerous improvements have been made. These improvements included replacement of the propane-generator power supplies with solar cell power supplies, upgrading and expansion of the TCS computer, the addition of multi-function antenna systems for improved coverage. All of these changes were made while conserving the basic modulation and signal design, thus preserving the interoperability and interchangeability of all the RMS systems (with the exception of the 435 MHz system of Fort Bliss, Texas).

Several years ago, GDE undertook to develop a signal design which would allow a range tracking and data system to operate in the projected electronic warfare environment of the 1980's training scenario. This work resulted in the design of the system described in this paper. The new signal design comprises a nonlinear chirp-type spread spectrum with pulse-position modulation (PPM) encoding of data, resulting in high data rate and improved operating range relative to the basic RMS systems.

Key factors and parameters considered in the selection of this signal design included:

1. Selection of carrier frequency.

2. Spectral bandwidth.

3. Use of asynchronous or synchronous network operation.

4. Message encoding/decoding techniques.

5. Tuned RF or superheterodyne implementation.

6. Processing gain and A/J characteristics.

GDE produces and has in operation range tracking systems at frequencies of 141 MHz, 435 MHz and 918 MHz. Consideration of size, weight, and the potential for in-band interference on over-land applications mitigated against use of 141 MHz. Frequency allocations and operational systems exist on land ranges at both 435 MHz and 918 MHz frequencies. The use of carrier frequencies at both these frequencies was pursued to the point of assuring feasibility of either approach. Since implementation of the new design at 918 MHz posed the greater challenge, that approach was carried forward. If a 435 MHz system were required, only the RF sections and antennas would require new design, analogous to the approach previously implemented for the Fort Bliss RMS system.

Various spectral bandwidths were considered. To maximize both processing gain and interference rejection, a bandwidth of 40 MHz was desirable. However, the existence of common threat transmitters with frequencies near 900 MHz posed the potential for strong in-band interference in the very scenario the system was designed to operate in. Based on this and other considerations, a bandwidth

of 10 MHz was selected. This choice had the further advantage of allowing maximum carry-over of current RMS designs.

GDE has long advocated the use of asynchronous interrogate-respond networks for range tracking systems. This approach allows for complete flexibility in numbers of participants, update rates, real-time adjustment of scenario changes, and elimination of the need for every participant to maintain a separate but synchronized clock. The potential applications of the Advanced RMS gave us no cause to change that advocacy, so the system uses asynchronous interrogate-respond network operations.

A surface acoustic wave (SAW) device was selected to generate a spread spectrum signal at the transmitter and to provide a matched filter at the receiver. Pulse duration was set at 10.5 microseconds and pulse position modulation (PPM) was utilized to achieve the desired message data rate of 297 kilobits per second. Tuned RF (TRF) implementation was preferred to reduce the parts count and size of the receivers and transmitters of the Advanced RMS, and would likely be implemented on a 435 MHz system. However, the state-of-the-art in SAW device production at GDE appears to dictate a superheterodyne implementation at 918 MHz.

SIGNAL STRUCTURE

The signal structure of the Advance RMS is fundamental to its applications in EW environment. A spread spectrum signal with pulse position modulation (PPM) encoding is employed for all transmissions. A signal bandwidth of 10 MHz at 918 MHz carrier frequency is used with a nominal pulse duration of 10.5 microseconds. This produces approximately +20 dB of processing gain, resulting in substantial immunity to EW interference. Since the purpose of the system is to provide tracking and digital data communications with cooperative (transponder-equipped) participants, intentional jamming of the 918 MHz ±5 MHz frequency is not anticipated.

The Advanced RMS uses an asynchronous interrogate-respond network technique which does not require synchronized clock or dedicated time slots for each participant. Each unit has a discrete address and responds only to messages coded to that address. Each unit is uniquely addressed by the Central Station, specifying the function to be performed. The unit addressed immediately performs that function, and no new commands are transmitted from the Central Station until a response is received (or a "no response" time expires). In this way, the interrogate-response system automatically adjusts its timing to accommodate varying lengths in both the data messages and the propagation paths to operate at maximum efficiency.

The Advanced RMS system interrogation messages are originated by the Central Station and have two purposes. The first purpose is to initiate the process of obtaining range measurements between participants to determine their positions. The second purpose is to transfer data to a participant and obtain data from the participant. An uplink message is addressed to a specific participant designated as a Reporter. The message may be transmitted directly from the Central Station to the Reporter participant if they are within line-of-sight (LOS). If not, other participants may be designated as relays to provide LOS communication paths. A Relay participant detects its address in the received message and retransmits the message, deleting its address. The Relay then waits for the downlink message to be received.

The addressed Reporter accepts data when present in the received message, and passes them onto the host vehicle. If the contents of the message indicate that range measurements are to be made, the Reporter initiates the range measurements to other participants by transmitting a message to each of the participants and waits for a reply. This message is originated by the Reporter and addressed to a participant designated in the message as a Responder. The participant designated as a Responder retransmits a range pulse to the Reporter that initiated the ranging operation. The Reporter measures the round-trip time to the addressed Responder, and the measurement is transmitted in a downlink message to Central Station. The Reporter also includes any downlink reply obtained from the vehicle in the downlink message when such data is requested in the uplink message.

The message originated by the Central Station contains the address of each participant that must react to the message in the order each is to react to it. An addressed participant designated to be Relay 2 will delete its address from the received message, change the designation for the next participant address to be Relay 1, and retransmit the message.

Addresses of up to four Responders to be used for ranging operations by the Reporter can be included in the uplink message. An additional four responder addresses can be stored in the Reporter to provide a total of eight range measurements obtainable by the Central Station with one interrogation message.

A participant which acts as a relay in a message path can also act as a Responder. Thus, a Relay 1 could also be one of the Responders for a Reporter. This is also true of the Central Station.

The Advanced RMS system employs pulse position modulation (PPM) to convey information. The information associated with each pulse is contained in the time position of that pulse relative to the preceding pulse. There are seventeen possible pulse positions. One position is reserved for the preamble of each message; the other sixteen positions are used

to convey four binary bits of information per pulse. Table 2 lists the pulse spacing allocations and the bit pattern or function assigned to that spacing. With this assignment, the average distance between pulses is 13.47 microseconds, resulting in a data rate of 297 kilobits/sec.

TYPICAL APPLICATION

The RMS/SCORE is presently deployed at the Nellis AFB North Range in support of the EW/CAS joint tests. This scenario is used here as typical of an EW exercise application for which the Advanced RMS would be employed.

The Electronics Warfare during Close Air Support (EW/CAS) exercise is a Joint Service Test to evaluate the effectiveness of electronic warfare during CAS operations in a mid-intensity conventional conflict. The participants in the exercise include 27 ground threats or threat simulations, and up to 28 airborne participants of various types, i.e., helicopters, Wild Weasels, FAC aircraft, A-10's, and various support aircraft. The RMS/SCORE system provides position location on all participants, tracking and displaying them in real-time for command and control. In addition, digital event data is collected from each participant and transmitted to the CS for processing and display.

To meet the real-time accuracy requirements, the required update rates are 5 updates per second

for the high performance aircraft, 2 updates per second for the helicopters and one update every 4 seconds for the ground units. Each update consists of the collection of six ranges and an average of two data transmissions. In this scenario and configuration the RMS/SCORE system utilizes approximately 92% of the available air time.

For the identical configuration, the Advanced RMS utilizes only about 54% of available air time. This improvement is primarily due to the group ranging capability of the Advanced RMS. In this mode, a transponder can collect up to eight ranges from the transponders, then send the set of ranges back to the Central Station in response to a single Central Station command. The improvement in digital data communication is even more dramatic. The Advanced RMS has approximately 5.5 times the data capacity of the RMS/SCORE and other RMS systems.

The RMS system in this exercise is used to provide both air-to-ground and ground-to-air pairing. The air-to-ground pairing is used between Wild Weasel Aircraft and the ground threats. Specified ground threat simulators are instrumented with transponder units and are polled once every 4 seconds to determine their tracking status and their azimuth, elevation, and range if they are in Track or Command and Guidance (C&G) mode. The aircraft in the exercise carry a simplified version of the AIS pod;

Table 2. Summary of Major Features of Advanced RMS

CARRIER FREQUENCY	918 MHZ (435 MHZ OPTION)
MODULATION	SPREAD SPECTRUM/PPM
TRANSMITTER/RECEIVER POWER RATIO (FOR RANGE MEASUREMENT)	143.5 DB
LINK MARGIN IMPROVEMENT (FOR RANGE MEASUREMENT)	24.7 DB OVER RMS
MAXIMUM RANGE WITH 0 DB ANTENNA GAIN	166 NMI @ 918 MHZ
SYSTEM DATA THROUGHPUT	235 KBPS
SYSTEM DATA THROUGHPUT IMPROVEMENT	5.5 TIMES OVER RMS
EW IMMUNITY IMPROVEMENT	GREATER THAN 20 DB OVER RMS
SYSTEM CAPACITY IMPROVEMENT (NUMBER OF PLAYERS)	70% OVER RMS

if a Wild Weasel simulates a Shrike or HARM firing, the RMS system detects that event through a status bit in the next range response. The computer immediately examines the status of possible targets. If a potential pairing exists, the RMS system displays that event in the Display Subsystem and simultaneously signals the targeted threat(s) via the digital data link that an antiradiation missile has been fired. Scoring in this case is done post-flight, utilizing full fly-out missile simulations and taking into account subsequent actions by the ground threat crew. The Computational Subsystem of the Advanced RMS will also be able to support real-time fly-out simulations.

Similarly, the RMS system supporting EW/CAS is tasked to perform ground-to-air pairing. Whenever any of the instrumented threats is in track or C&G mode, the system determines which aircraft are in an az-el-range window and displays the results on the Display Subsystem. Again, for EW/CAS, real-time fly-out models of the surface-to-air weapons are not used, since detailed analysis is to be done post-flight. However, the Advanced RMS could support ground-air weapon simulations for real-time casualty assessment. The Advanced RMS can be adapted to accomplish several modes of electromagnetic combat (EC) training. Each mode can be carefully matched to the sophistication

of the installed aircraft equipment and the level of readiness training required.

The Advanced RMS is designed for use on an Electronic Warfare (EW) training range. The basic subsystems provide the required reference track for the participating aircraft. Transponders can be installed on all the threat hardware, including mobile AAA units, mobile surface-to-air missile (SAM) systems and semi-fixed systems. The transponder serves two purposes: first, it provides the reference position of the EW threat; second, its data communications capability can be used to transmit weapons status (i.e., search, track, launch) and rada. information (i.e., range, azimuth and elevation). With this information, the CS can use realistic SAM and AAA simulations to provide instantaneous probability to kill data for any given engagement.

The increased transmitter power and processing gain of the Advanced RMS transponder make it an even more effective tracking system in an EW environment than the RMS/SCORE. Table 2 summarizes the major features of the Advanced RMS in comparison with the RMS/SCORE. These features make the RMS system with the Advanced RMS transponder the tracking system to support EW training in the future, as the present RMS system has supported such training in the past and present.

A PRACTICAL C³ AND C³CM TRAINING SYSTEM
FOR THE 1 MHz TO 1000 MHz RANGE

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ABSTRACT

To evaluate the performance of operators and measure critical C^3 equipment under "real world" signal environment conditions, it is necessary to test with the quantity and variety of emitters expected in actual situations. A method is discussed which has been developed to simulate realistic C^3 and C^3CM signal environments in the 1 to 500 MHz range, as well as TACAN and JTIDS signals in L-Band, for use in operator training programs.

BACKGROUND AND SUMMARY

The ever increasing density and interaction complexity of the Command, Control, and Communication (C^3) environment and its Countermeasures (C^3CM) makes severe demands on modern Electronic Support Measures (ESM), Signal Intelligence (SIGINT), and Countermeasures (CM) systems. Measuring the behavior of trainee operators using C^3 and C^3CM equipment under "real world" signal environment conditions requires evaluation with the quantity and variety of emitters expected under realistic situations. Although test and evaluation with this actual emitter environment is desired, the logistics of assembling and orchestrating the variety and number of emitters and modulations that would be encountered under field conditions can make full-scale scenarios and replication of tactical situations expensive, if not impossible.

Other means of tactical environment simulation involve computer and operator interactions, such as synthetic control/display training devices, software scenario simulation, and signal environment simulation. Of these techniques, only signal environment simulation offers the vital capability of training with actual receiving, recognition, and reaction equipment. Techniques for accomplishing a realistic training signal environment simulation will be discussed. They include the hardware for signal generation as well as the software for signal control and scenario development.

Signal environment simulation consists basically of creating the same aggregate signal that would result from an actual deployment of real emitters in real space and time. This is accomplished by a computer-controlled, time-ordered initiation of the frequency, level, and modulation format of multiple independent RF sources, which are then combined to form a composite signal environment. The most effective use of standard control interfaces such as RS-232C and GPIB (IEEE-488) will be discussed, along with methods of signal environment generation that take maximum advantage of hardware capability.

In addition to signal environment simulation for a variety of tactical EW cases, the presentation will discuss various configurations of a signal simulator system that allow creation of special effects such as doppler, multipath, and signals in the presence of broadband or narrowband noise and deceptive jamming signals.

Philosophy of SIGINT Operator Training

A simplified diagram of a COMMINT operator training technique is shown in Figure 1a. From the standpoint of the Communications Intercept operator, the primary characteristics of the signal that are of interest are the Radio Frequency, modulation type and information content. Other parameters normally of secondary interest are the signal level, direction-of-arrival, and signal perturbations due to the propagation path or transmitter signature.

Although there are substantial differences in training methods, depending on operator type and the ultimate mission, the basic processes can be thought of in frequency domain terms as either of a baseband or RF-type training.
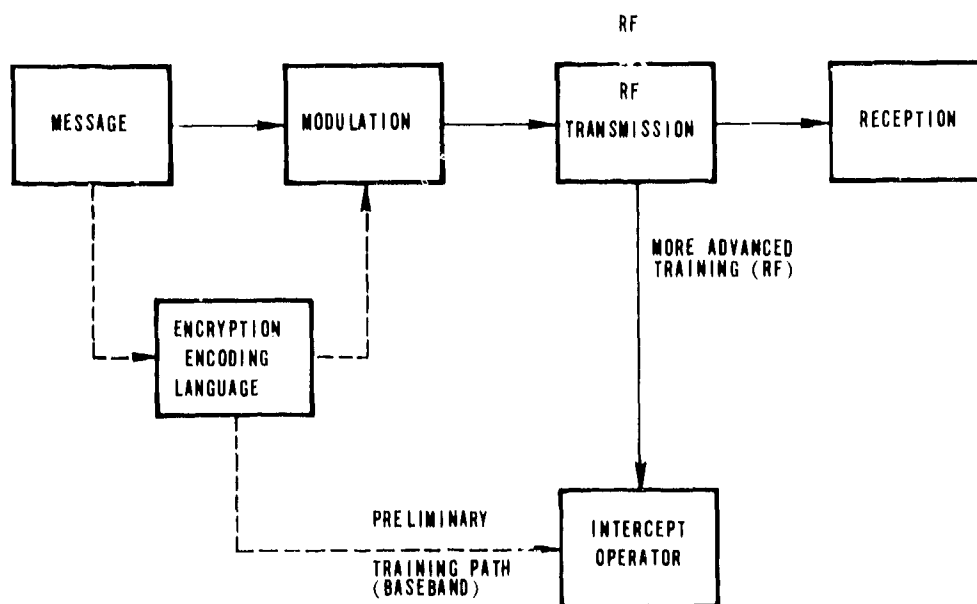
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Fig. 1a – Simplified System Model for
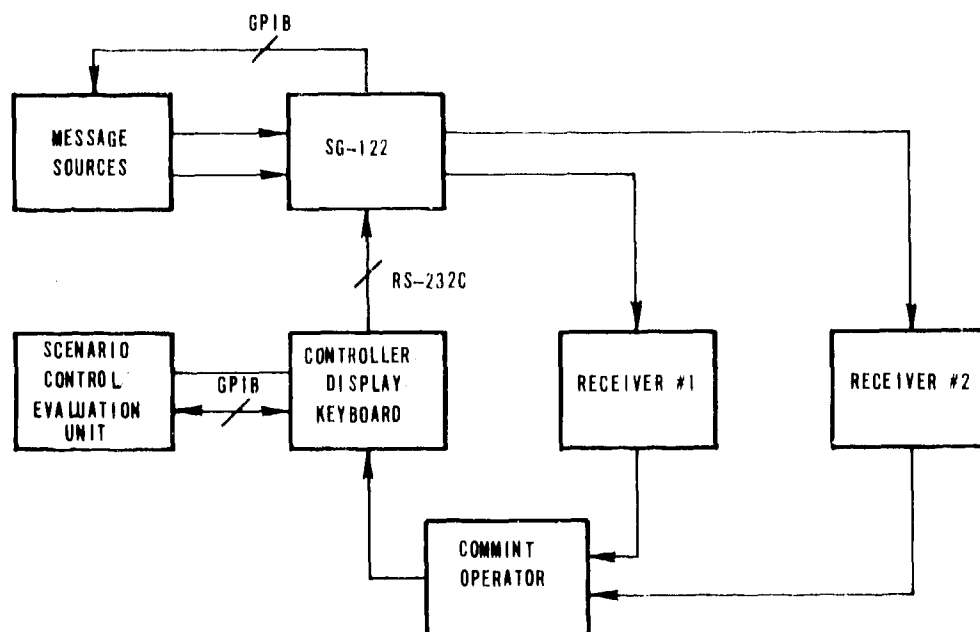Basic COMMINT Operator
Training

Fig. 1b – Realization of a Simplified COMMINT Operator Training Setup
Capable of Preliminary and More Advanced RF Training

Baseband Training

Baseband-type training generally is preliminary in nature, usually relatively low-cost and simple to implement. Its use is mainly to train operators in encoding/decoding (e.g., audible Morse Code) or language translation (e.g., taped conversations). A more advanced quasi-baseband training process can be broadly called computer simulation. With computer simulation, a set of conditions or status indicators is presented to the trainee, usually in character or graphic format via a CRT console. Trainee responses to the conditions elicit pre-programmed responses from the computer or synthetic control/display system. The illusion of a running scenario can thus be created, but the trainee is not using "real" COMMINT equipment, and the "signals" are complete preverications.

RF Training

Enter RF training Techniques. Generally these are more costly to implement because of the modulation and RF carrier generation required as shown in Figure 1a. The alternative to controlled RF training techniques is "on-the-job" training which is probably the most effective of all, but which can be very costly or have devestating results if training is inadequate.

A Cost-Effective SIGINT Simulation System

The basic challenge of effective SIGINT equipment operator training is to provide RF intercept practice that closely approximates a real life RF enviror.ment (Figure 2) which can be controlled, duplicated, performance monitored, and critiqued. The assemblage of equipment to accomplish this has previously been extremely costly, partly due to the central computer control and the software to support scenario generation, but also because of the expensive RF sources required.

Two years ago, LOCUS embarked on a program to realize hardware to implement a low-cost, programmable wide-range RF source that was capable of producing a wide variety of modulations with at least 50 dB spurious-free dynamic range. This equipment has now been in the field for over a year in

test and evaluation applications. It is modular in concept and with appropriate software is adaptable to several levels of SIGINT operator training as described below.

COMMINT Operator Training Setup

A realization of a simplified COMMINT Operator Training Setup using the SG-122 and a low-cost controller/display/keyboard (hp-85) is shown in Figure 1b. The flexibility of the SG-122 for rapid frequency and modulation parameter change permits the simulation of very complex signal environments as seen by the trainee's receiver, utilizing a single SG-122. Its dual independent output signal capability enables the generation of signal environments that include adverse interference situations such as jamming and very dense signal conditions. This basic setup provides CW, AM, FM, PSK, FSK, and SSB signals with computer-controlled carrier frequency, modulation type and index, as well as signal level. The operator response is noted by the Scenario Control/Evaluation Unit which can be as simple as an appropriately programmed desktop calculator. The Control/Evaluation Unit provides an Instructor interfacing to enable monitoring performance and modifying the training sequence as necessary.

Interactive SIGINT Training

Although a single SG-122 Signal Simulator/Programmable RF Generator and associated peripherals can provide advanced RF training for complex RF environments at very reasonable cost, creation of complete interacting capability requires additional equipment when more than one trainee operator is involved. One possible realization of a training environment that provides multiple simultaneous signals to multiple trainee operators in an interactive arrangement is shown in Figure 3. It is easily expandable to accomodate more operators or special background environments by adding additional signal sources.

The interactive system of Figure 3 is highly versatile in the types of signals that can be generated, and requires only software changes to tailor the RF environment as desired. Since the simulation system is modular, it can be scaled from one to many simultaneous trainee operators. If desired, each
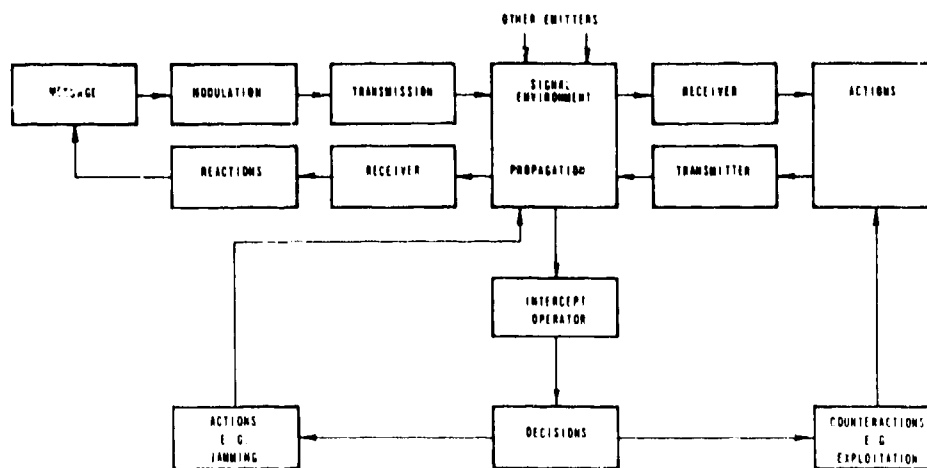
71

Fig. 2 - Interactive Nature of the SIGINT Operator in a
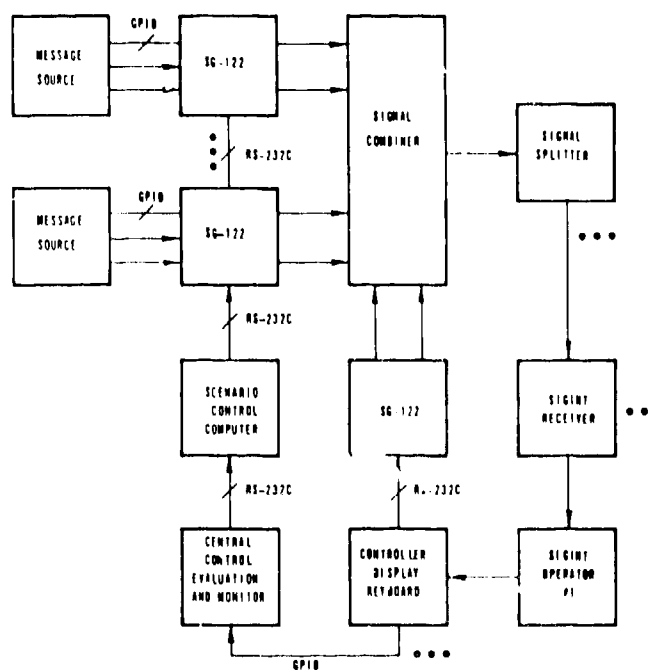Realistic Communications Environment

Fig. 3 - Realization of an Interactive Communications
Environment for Multiple Operator Training
With Multiple Simultaneous Signals

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environment can be individualized or supplied collectively as shown. The use of both RS-232C and GPIB (IEEE-488) control busses makes interfacing to standard computer peripherals and GPIB interfaceable test equipment straightforward.

CONCLUSION

A modular, versatile system for RF environ. simulation has been presented, which should allow much more cost-effective SIGINT operator training than has previously been possible. Multiple signal, multiple operator interactive capability is available with software control which can be adapted for most conceivable training and test applications.

INTEGRATED ENVIRONMENT SIMULATOR

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INTRODUCTION

● All modern defense forces of the free world require the employment of sophisticated electronic equipment by highly skilled personnel.

● The operational readiness of these defense forces depends, in part on personnel training, properly maintained equipment, and the knowledge that equipment and personnel are in peak condition.

This preamble expresses Antekna's understanding of the critical need for unit operational readiness in all of our military services. We believe that fully supported, easily operated total electromagnetic environment simulators operated as turn-key systems offer viable solutions to the problems of test, evaluation and validation of operational threat warning receivers, jammers, reconnaissance, and surveillance equipment, as well as the training of personnel in the effective use of this equipment in a coordinated modern defense operation.

By total integrated environment simulation, I mean the ability of the simulator to recreate all current and likely to be developed emitters (or conversely the sensor response to these emitters) that conceivably could be employed in tactical situations. This means not only the required parametric simulation of each of the individual emitters but also the total spatial, temporal, and parametric interrelationship among these emitters.

In addition, there is the further requirement that the simulator have a man/machine interface of such sophistication that operational personnel or training/ instructor personnel can exercise these simulators to the full extent of their capabilities.

Equipment is being designed and built to ever-increasing limits of sophistication. Many of these equipments are being integrated into larger systems managed by computer intelligence. A new word has evolved in equipment design – technology insertion. Taken loosely, this means that all new designs have built-in flexibility for hardware and software modification to counter ever faster moving development by the enemy.

With such sophistication and complexity, and with many of the routine decisions being made by computer, it is imperative that these equipments undergo periodic evaluation to ensure that they are providing the tactical commander with proper, accurate and timely information. When hardware and/or software modifications are incorporated, there must be thorough validation of the modifications to ensure they are performing the tasks intended and have not degraded overall performance.

Current tactical commanders are confronted by such technological sophistication that they can't or won't effectively use the equipment. There is insufficient time for a commander to become both tactically and technically competent. Training is an absolute must if we are to make the total tactical system effective.

The key to success in many of these test/validation and training missions will lie with the simulator. It will be asked to accurately replicate the total electromagnetic and electro-optical environment that could conceivably be encountered in future tactical operations.

Through his sensory equipment, the tactical commander is subjected to a multitude of radar, communication, electro-optical, and ECM data. The enemy is proliferating his operations with large numbers of equipments ranging from the newest state-of-the-art optical equipment to vintage radars. The environment is compounded when one recognizes the proliferation of our own and friendly forces' emitters that are also operating in the same tactical area. The enemy's electronic order of battle is disciplined and well coordinated, and from the detection of these activities we hope to gain the tactical advantage of foreknowledge of his probable purpose and the proper response to maximize the probability of survival. But rarely does the enemy display the actual EOB he intends to use in tactical operations. Therefore, there must be a mechanism wherein the tactical commander can be exposed to the myriad combinations of electronic activity which

could confront him in a tactical situation and allow him to experiment with responses to find the optimum reaction. There are projects in process (e.g., BETA[1]) which are attempting to provide this capability.

Because of the density and complexity of this environment and with the added dimension that the enemy will use electronic countermeasures to further confuse the situation, it is imperative that sensory equipment be proven in a realistic environment. This is particularly true where the equipment contains intelligence that makes decisions on emitter-type classification and priorities. Density, similarity in parameters of widely different emitter types, and the use of ECM all contribute to the probability that wrong decisions will be made and the commander supplied with improper information.

In each of these missions, the simulator will be a large factor in success or failure The simulator must be accurate in the recreaof individual emitters as well as accurate in the recreation of the parametric, spatial, and temporal interrelationships among the emitters. It must be flexible so that large variations in scenarios (e.g., large variations in emitters and their interrelationships) can be easily simulated. And one of the most critical requirements is ease of

operation: the need for a high-level interface that will allow user personnel with minimal training to operate the simulator to the full extent of its capabilities.

SCENARIO

I will now turn to the use of a hypothetical example to illustrate the concept of total environment simulation and tie it to the missions of test, evaluation, validation and training as well as focus on the critical need for operability and maintainability.

A typical C^3CM mission might involve such tactical decisions as: exploiting the emissions, jamming them, deceiving them, or destroying them[2]. This decision could be made by a Tactical Air Commander or a commander at the FEBA. Whichever we choose will not effect the example for both are primarily focused on tactical operations. We chose the TAC. In this example, the TAC will receive data from threat warning receivers, surveillance receivers and will have at his disposal (figure 1) on board jammers, ground based jammers, and weaponry at his command.

The threat warning receiver is used to give automatic identification of emitters, their position and density as well as provide input to the self protection jammer system.
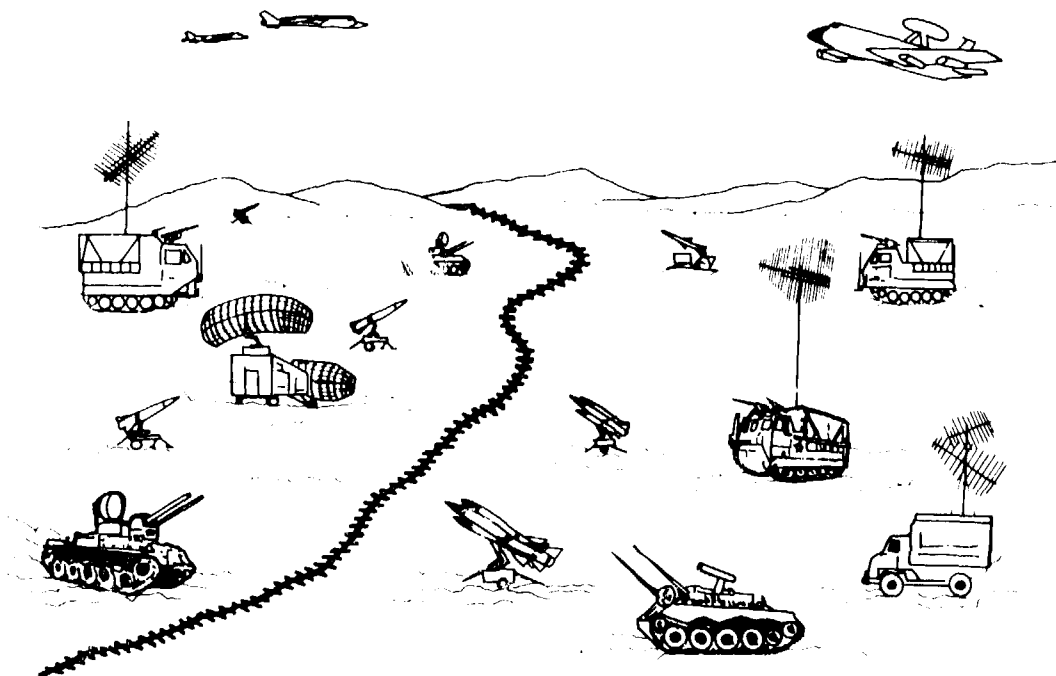

Figure 1. Tactical Scenario

These receivers are sensitive to radar, communications and laser emissions. In this example, the warning receiver has the capability to observe correlations between radar and communications activity and radar and laser activity to increase the effectiveness of the ECM activity.

There is a handoff function between the receiver and the on board jammers wherein certain priority emitters are automatically jammed. Between the receiver processor and the jammer processor the decision is made on what to jam, how to jam, and effectiveness of the action with feedback to modify action.

The surveillance receivers provide more detailed analysis of radar, communications and jammer emissions. Because of a-priori knowledge of the enemy's electronic order of battle, data supplied by these receivers give the TAC indicators of enemy intent. From this data he will make one of the four decisions: jam, deceive, exploit, or destroy. These receivers also provide measures of effectiveness of his actions.

Therefore, the integrated environment simulator must accurately replicate the large numbers of individual emitters - radar, communications, jammer, and laser - each with its own unique parameters. And beyond that,

it must be capable of replicating the almost infinite variety of spatial, temporal, and parametric interrelationships between these emitters.

The threat generator (figure 2) will recreate all the complexities of current radar technology such as frequency agilities, and prf agilities. It will also accurately replicate antenna scan effects as well as propagation degradations. Parametric interrelationships within a given emitter or among a set of emitters will also be simulated, for example, scan as a function of frequency, or scan as a function of prf, or the progression of a system through search, acquisition, and track. The threat generator is capable of performing extremely complex and dense scenarios with accurate replication of spatial and temporal relationships. Emitters can be turned on and off, moved and flown.

The ECM simulator (figure 3) replicates the basic signal characteristics found in noise and deception jamming techniques.

The noise jamming simulator will recreate such parameters as frequency, width (spot or barrage), or a sweep of frequency. It will have the capability to add modulations to the noise characteristics. The deception simulator will recreate current
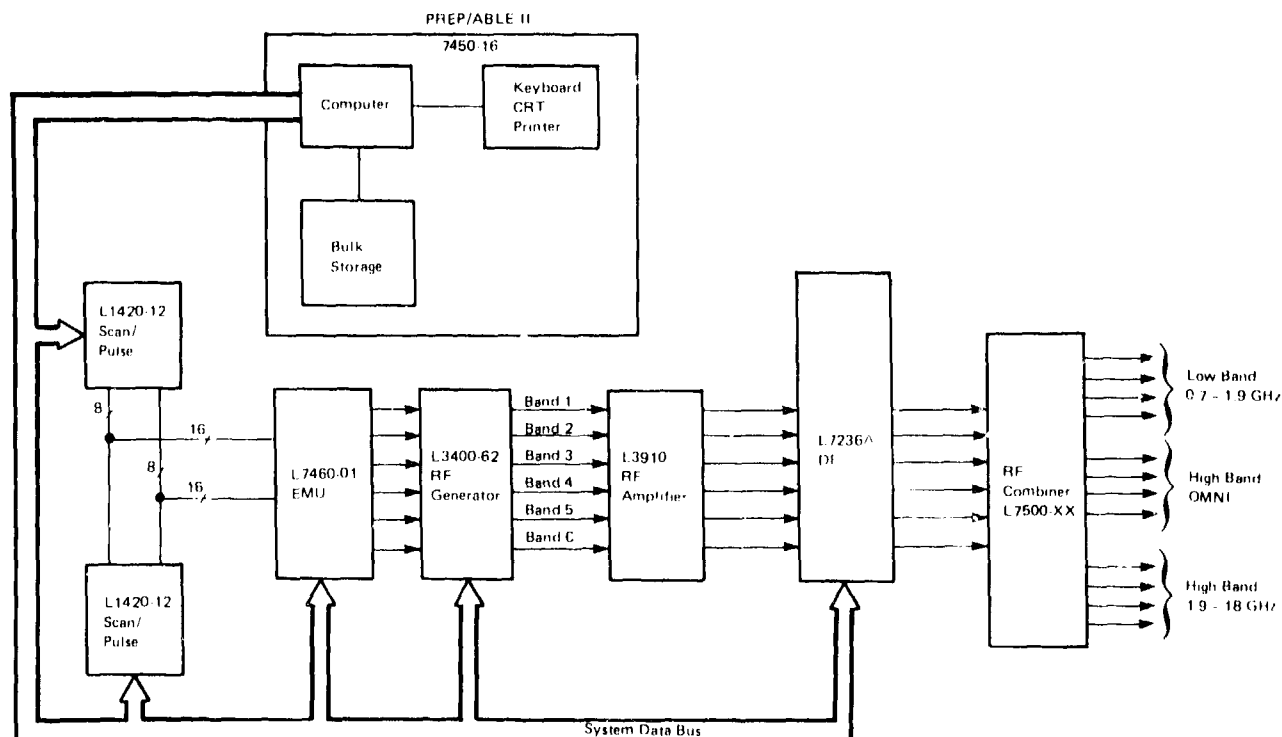

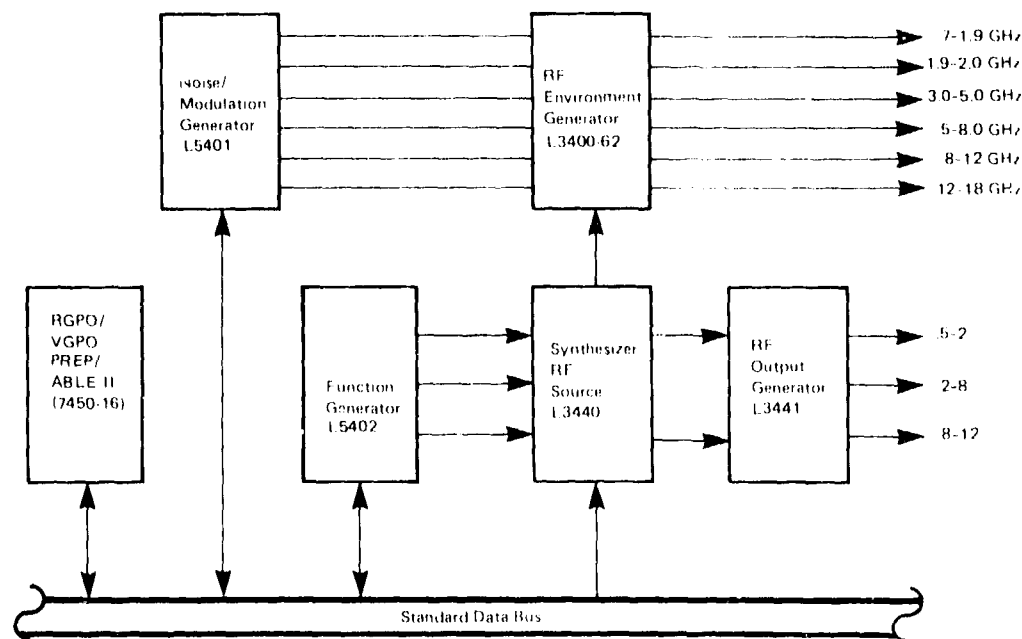Figure 2. Standard Emitter Simulator (STEMS)

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Figure 3. ECM Simulator Block Diagram

range and velocity gate pull-off techniques as well as modulations.

The communications network simulator is capable of recreating the extremely dense spectrum of communications emitters encountered in a tactical operation. It recreates the element of control, information creation, information processing, signal generation, signal propagation, signal environment, and security, keys to all tactical communications networks.

The communications network simulator (figure 4) replicates message generation, message processing, RF generation and processing, and RF environment for a large number of communication emitters. The message generation and processing capabilities allow simulation of voice, TTY, or Morse signals with recorded or synthesized information content. The recorded or synthesized voice can be any language. It also routes this information to selectable modulation simulators such as PCM, FDM, etc.

This signal can now be applied to a specific RF frequency with amplitude and phase modulation control to simulate propagation effects. Background signals can also be generated and added to the output to recreate a realistic spectrum of signals.

Simulation of the optical environment (figure 5) is still in the developmental stage. Current projects have indicated that the bragg cell and acoustic-opt filter could provide mechanics to achieve accurate replication of optical parameters; i.e., color, spectral characteristics, modulation, direction-of-arrival, and propagation effect.

I would like to emphasize a point: Notwithstanding the need for accurate simulation of each of these emitter areas independently, the critical need is for the accurate and total simulation of these individual areas and their very specific tactical interrelationships. It is in the recreation of these specific interrelationships that we add the realism required for our training and test/validation missions.

Given that individual emitter action can be very important to the tactical situation, it is very important to know that a missile was just launched against you. The key to tactical success lies in the information contained in all of the emitter operations. There is discipline in any tactical encounter. Therefore, the closer to the initiation of any operation that the tactical commander can become aware of the situation, the more time he has to generate his response. This, at least theoretically, should translate into higher probability of success.
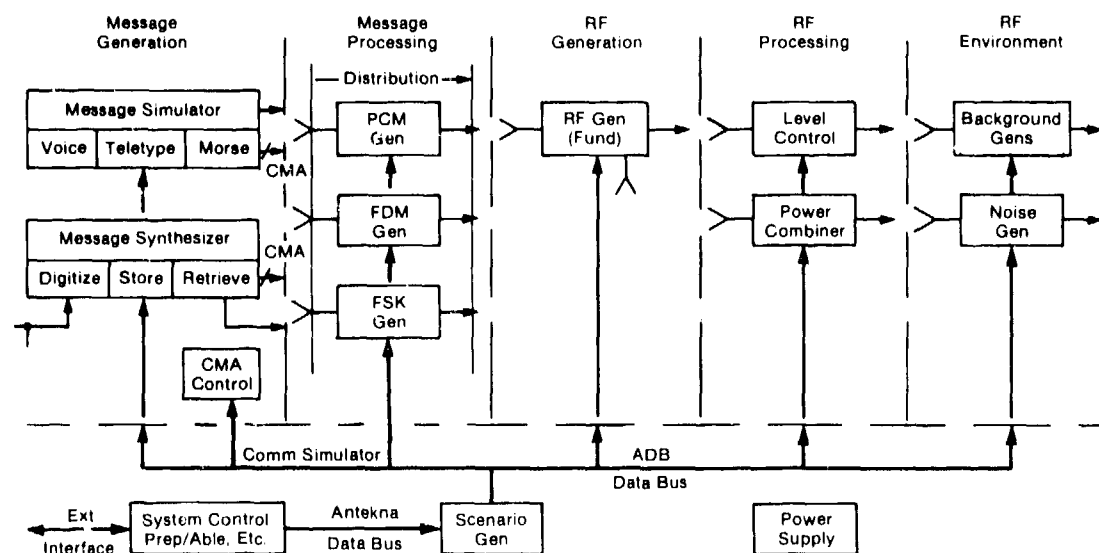
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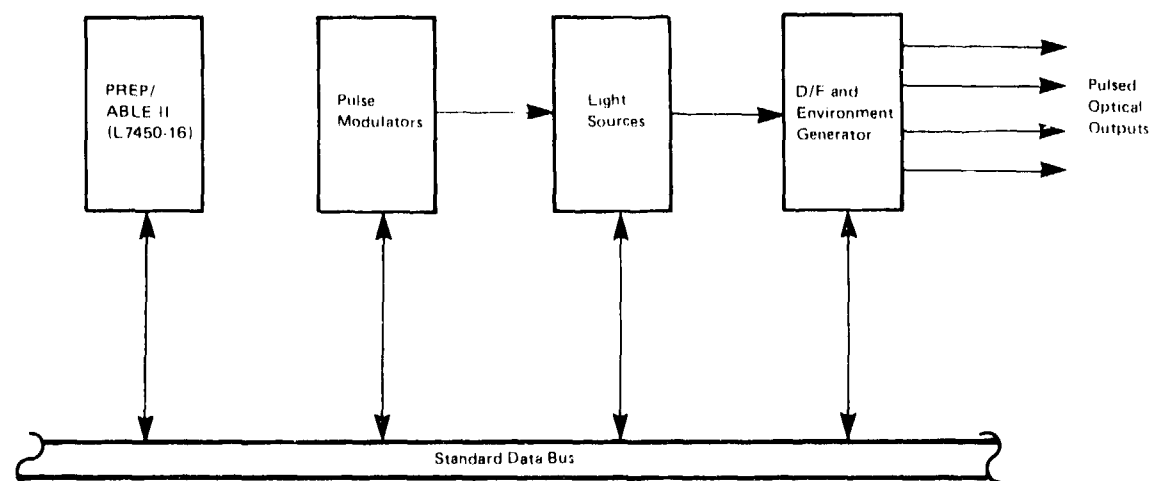Figure 4.   Front-Level Scenario Communication Simulator Functional Blocks

Figure 5.   EO Simulator Concept Block Diagram

Typically, the in lation of an action does not occur with a missile being launched but with heightened communication network activity along with increased radar activity, and possibly electronic countermeasure employment. Both sensor equipment and information evaluation must be up to the task of correctly recognizing and interpreting this activity.

Since we are never sure of the exact theme or variation an enemy intends to use in actual operation, the equipments and commanders must experiment with large numbers of themes and variations to help develop a catalog of responses that can be instantaneously implemented and which have been programmed to be successful.

These themes and variations continue as the operation unfolds and the environment continually changes. Different emitters come into play: acquisition and track radar, missile guidance radar, electro-optical, outpost communications networks, and more jamming, all coupled with friendly electronic activity. Again, the equipment and commander must be up to the task of making the right response.

To this point our example has discussed the why and what of integrated environment simulation, now we turn to how.

How we approach integrated environment simulation will be greatly influenced by the mission it is to perform. In our example are we primarily interested in determining that our equipment is in operating condition? Are we interested in validating a change in processor software or hardware modification? Or are we interested in the training of the TAC in operational decision making?

The approach I will describe is based on a building block methodology. The implementation of the simulation system begins with a man/machine interface that drives a variety of generators from total software packages to full RF and optical packages. When we move from system to system only portions of the simulator will change, much will remain constant. The most important feature of the system that remains initially constant is the man/machine interface.

Regardless of the mission to be performed, the key ingredient is the man/machine interface. When we talk of total integrated environment, by definition we are considering a large number of emitters that are continually changing state of operation or position. The initial effort required to generate a meaningful scenario will be a substantial task, first in defining what the scenario should be and then programming the simulator to perform the scenario.
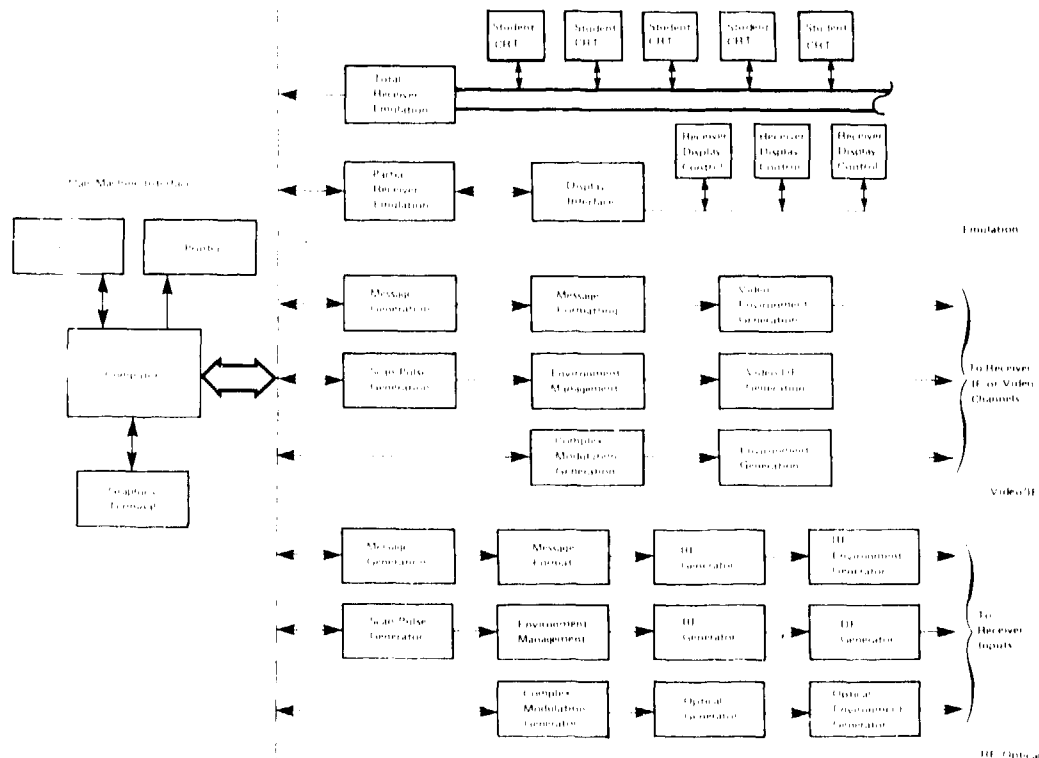

Figure 6. Integrated Environment Concept

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The people who are to program this equipment do not have time to become expert in the detailed workings of the simulator. There must be an interface that is easily learned, easily retained, and that allows the operator full control of the system. These two problems then dictate that the simulator contains a high-level man/machine interface.

This interface should respond to language that is familiar to the operator and designed to facilitate the performance of his task. It should contain a prompting feature so that he has a method of recall readily available to him.

In many of the missions, particularly training, flexibility in scenario generation and modification will be a key requirement. Much of the scenario modification will be in real time: instructor seeing student make a mistake - stopping the scenario and redoing a portion. To do this, the interface will require a real time edit capability.

In addition, the operator needs identification on the status of the simulator, the execution of the scenario, and perhaps a record of the simulator outputs. The first two are primarily housekeeping functions, indications that the simulator is performing and where it is in any particular scenario. The last, however, could be vital to a test or validation mission. There is always the question of which is right, simulator or equipment under test? With a time-phased record of simulator output, equipment input and output can be compared and the question resolved.

Now that we have the method of interface, to what do we interface. Remembering that a large portion of the job has been done in the development and implementation of the scenario, the built-in test and feedback on the status of the simulator, we turn to the generation of the scenario.

If we are primarily interested in training the TAC's of our hypothetical example in a classroom situation the generation of our scenario might be accomplished entirely in software. The heart of our man/machine interface is an expandable, fast computer. Therefore, to implement a total software emulation, the computer's memory, processing and peripheral capabilities is expanded and the required software modules added.

In our example, typical software modules might be:

● emulation of the warning receiver

● emulation of the on-board jammer

● emulation of the ground jammer

● emulation of the surveillance receiver

● display of spatial and temporal environment

● interaction interface for inputting TAC decisions

● evaluation of actions

There would probably be a number of these in a classroom situation with a number of TAC's undergoing training.

Now let us extend our idea of training to the concept of coordinated crew training. In our example we have the TAC as the primary decision maker and a number of operators evaluating data from our receivers. The implementation could again be primarily software but with software driving real-life displays.

This could be implemented in a classroom, or a mockup of the vehicle or vehicles that the commander and operators typically find themselves in operational conditions.

For this method of implementation, some of the software is replaced by interface hardware which drives the displays and also converts operator control of the equipment back into software - the same function as performed as before, but here we have added the realism of actual hardware and coordinated operation.

Now suppose we were interested in software validation, proving that any change that we made in any of the receiver processor units did what we intended and did not distort any of the remaining processor algorithms. This takes two steps. The first involves validating only the change made; e.g., a new threat has been added to the EID table. And the second, validating the entire processor in a realistic environment to ensure that the new software has not affected the total operation of the system, e.g., priorities are correct, de interleave still works properly.

Since we are validating the software, the scenario that we create must provide realistic input into the processor. In most situations we could emulate the front end of the receivers with software and provide hardware replication of video or IF signals.

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As in our previous example, we are not changing the entire simulator system, but only that portion that emulates the receiver's processor units.

What if we wanted to test and emulate the entire system? To see the effects of harmonies generated in the input by very strong signals, to evaluate jamming effects ad infinitum. Then we could take one more step in our system and not emulate any of the receiver equipment but replicate all our signals at RF or optical frequencies. The man/machine interface remains the same.

The examples to date have an underlying assumption that we are in laboratory or classroom situation and the simulator is laboratory type equipment. But why not take this same concept and package it for field use? Now we have this same capability, man/machine interface to full RF replication in a field portable unit. This unit can go with operational units for continual training and to give the commander assurance that his equipment is in peak operating condition.

CONCLUSION

The real and immediate need to perform training and test/validation missions requires the simulation of the total battle environment. The simulator must accurately replicate the parametric, spatial, and temporal characteristics of radar, communications, electro-optical, and countermeasure emitters as well as the parametric, spatial, and temporal interrelationships between and among these emitters.

The approaches to simulation of the total environment vary as the mission requires. Many training missions will be satisfied by software approaches. Most test/validation missions will require forms of video injection and/or RF/optical generation. All approaches will require a high-level man/machine interface to allow operational personnel to operate the machine to the full extent of its capabilities. The interface will operate in language familiar to the user and will allow him to edit and modify scenarios and give the status of operation.

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[1] See Phillip C. Dickinson, "_ETA Project,"Electronic Defense, January/February 1979, pp. 41-45.

[2] See "The Joint EW Center" an interview with the Commander, Electronic Defense, January/February 1981, pp. 31-58.

COMMUNICATIONS READINESS TRAINING UTILIZING REALISTIC SIMULATION

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I. INTRODUCTION

The belligerent attitude of the Soviet Union and the continuing Mid-East crisis have shown the need for having the U.S. and allied forces well prepared and well trained. However, when you consider the high cost of fuel and Congress' requirement that fuel costs be cut in all services, it is clear that training cannot be accomplished by large-scale operational exercises in the field — it must be done with simulators that are realistic enough to create the stresses of wartime conditions while affording the economy of training in garrison.

To meet these growing requirements for training and test and evaluation, the Communications Network Simulator (CNS) provides:

* Simulation of operation comms at RF.

* Simulated message generation, message processing, RF generation, RF process, and RF background environment.

* Compatibility with non-comms simulation to provide a total signal environment.

* Modular "building block" architecture of a specific yet generic form that allows expansion from:

   Battalion level comms for unit training, with 35-signal HF/VHF scenario.

   Front level comms for section level training, with 750-signal HF/VHF/UHF scenario.

The impetus for development of this product line was the awareness that training and test and evaluation for equipment in the 80's will (1) require an increasing level of sophistication, and (2) reflect the fusion of the comms and non-comms environments.

Figure 1 depicts the signal environment trends for non-comms and comms signal types. The two classes are evolving such that in the 80's comms signals are increasingly non-comm-like in their machine-to-machine nature while non-comms signals are increasingly comm-like with network links.

NON-COMMS	COMMS
MACHINE-TO-MACHINE	HUMAN-TO-HUMAN
DISPLAY	REPRODUCE
CONTROL	COMMAND
ELINT	COMINT
ECN	ECN
NETWORK	

Figure 1. Signal Environment Trends

II. CNS DEVELOPMENT

A. The Model for the Communications Network

The communicator plans the function of his command and control. He does this by prescribing a set of communication networks, wherein he articulates functions of networks, network users, types of traffic, security procedures, frequencies, time schedule, and network control.

The following elements, as shown in figure 2, are key to all communications networks; hence they must be included in realistic simulation.

Control: The control function (operational doctrine is implemented by the communications officer) controls the information creation, information processing, signal emission, and security functions.

Information Creation: The information creation function includes all processes involving the transformation of information into a message (for example, the information may be an order, a recurring report, or a response to an earlier message) and the formatting of this information in conformance with prescribed doctrine.

Information Processing: The information processing function represents the translation of information created in the information creation process into forms amendable to signal generation. These forms include:

   Voice Data
   Manual Telegraphy
   Automatic Telegraphy
   Facsimile
   Video

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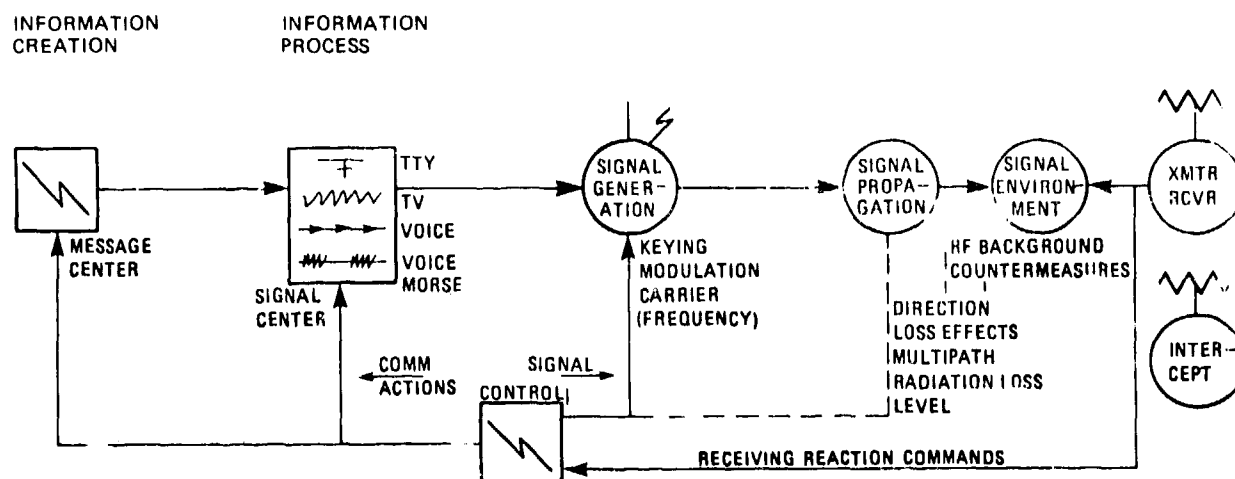INFORMATION   INFORMATION
CREATION   PROCESS

Figure 2. Comm Process Functional Diagram

Signal Generation: The signal generation function consists of those electronic processes that create a carrier signal and key or modulate that carrier signal with information provided by the information process function. Included within the signal generation function are the modulation processes, which create emissions such as A0 through A9 (amplitude-modulated signals), F1 through F9 (frequency or phase-modulated signals), and P0 through P9 (pulse-modulated signals).

Signal Propagation: With the exception of directional transmission, the signal propagation function is NOT consistently controlled by the communications circuit control function. Signal propagation effects include directivity, line of sight, multipath, doppler shifts, and level (range).

Signal Environment: The signal environment function is NOT controlled by the communications circuit control function. Signal environment includes a high density of background signals, natural and man-made noise, and hostile countermeasures signals.

B.   The Simulation Model

In fully implemented form, the Communications Network Simulator models all aspects of the threat emitter characteristics. Degrees of authenticity and sophistication are determined by user needs. The simula-

tion user has simple, direct means of interacting with the scenario.

The key features of this capability include:

● Scenario control, generation, and storage via digital control

● Message generation, text control, and storage via digital control

● Message processing for distribution of multiple message baseband signals

● RF generation of highly accurate RF carriers control

● RF processing and signal path effect simulation

● RF background environment simulation

A high degree of authenticity in the simulated communications network is thus realized by implementing simulation hardware and software in a one-to-one correspondence with communications functions, as shown in figures 2 and 3. A further expansion of the Communications Network Simulator functional block description is shown in figure 4.
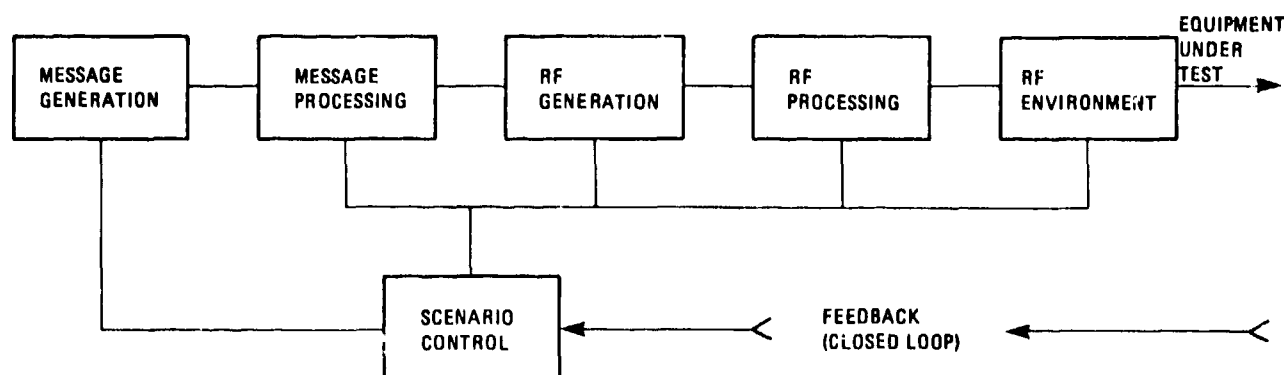
84

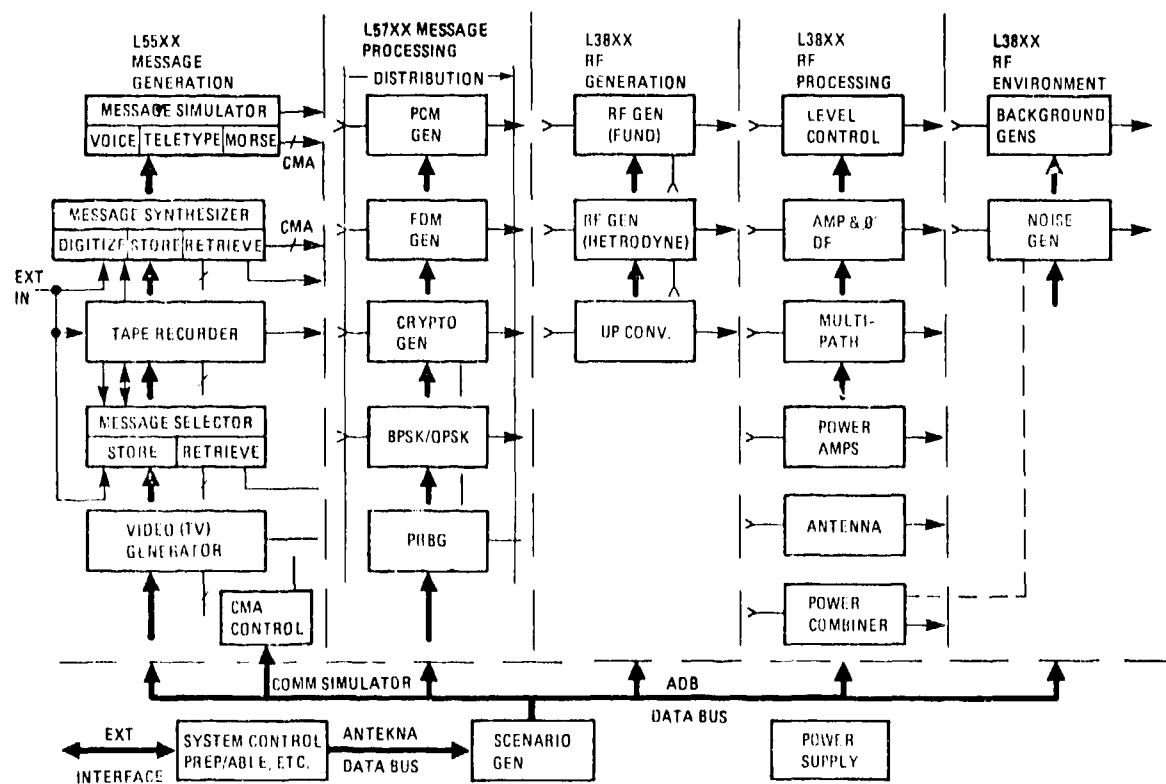Figure 3. Simulation Model Functional Blocks

Figure 4. Communication Simulator Functional Blocks

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C. The Feasibility (Hardware) Model

In June 1980, Antekna, Incorporated, provided a hardware feasibility model demonstrating the key features of the Communications Network Simulator, including:

- Programmable control with user-oriented language and stored scenarios that can extend to several hours.

- Message simulation that accurately simulates the form of multi-language, individual voice text with realistic voice characterizations.

- Fully synthesized, digitally controlled RF generation and processing.

- Background signals with appropriate modulations and density for simulation of realistic environments.

The block diagram and specification of the hardware model is shown in figure 5.

III. CNS APPLICATIONS

The CNS is primarily an intermediate level training device for communicators, intelligence operators, and intercept operators. Early demonstrations revealed a versatile and extremely accurate system ideally suited for the testing and evaluation of modern, computer-controlled, state-of-the-art ground, space, surface, and subsurface communications systems.

Training devices are tailored to the customer's requirements, or in some instances to the customer funding availability. With the modular approach, the small system can be enlarged or updated with greater capabilities to meet changing requirements or as funding improves.

Modern communications simulation is a necessary tool available to aid in the solution of difficult training problems. However, to be effective, the primary requirement of the communications simulation must be its ability to create a realistic environment. The Model 8520 CSS significantly increases the effectiveness of training by realistically replicating the total signal environment typical of a scenario, an ordered sequence of signal occurrences with durations from minutes to several hours.
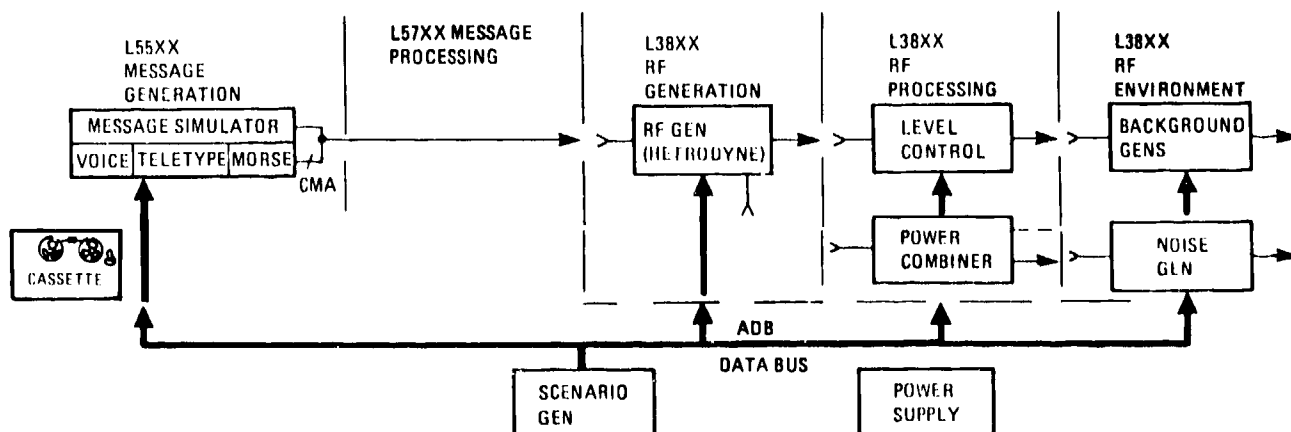

Figure 5. Block Diagram of the Feasibility Model

IV. FUNCTIONAL DESCRIPTION

Model 8520 CSS addresses the communications signal requirements necessary to maintain operator efficiency in the use of receiving equipment, language translation, and signal recognition. It offers flexibility in a wide range of capabilities that can be tailored to fit limited budgets and grow as funding and operational requirements increase.

Functionally the CSS includes three modular subsystems:

(1) Operator control interface, consisting of the bubble memory programmer, serial data interface, keyboard, and hardcopy printer.

(2) RF generator/processor subsystem, consisting of the RF generators, RF background generators for the exact simulation of environmental conditions, level modulators for path-loss generation, RF combiners, and noise generators.

(3) Message simulator subsystem for the simulation of message traffic on circuit, including digitized voice, TTY, and Morse telegraphy.

The system design enables the user to start with a basic system and expand to a system with a greater number of signals, more and different backgrounds, and other modulation capabilities as funding and/or operational requirements dictate.

Since each subsystem is composed entirely of off-the-shelf Antekna products, this expansion can be easily accomplished with a minimum schedule impact.

Basic Model 8520 CSS

The basic model CSS, as shown in figure 6, contains complete operator control interface with bubble memory programmer, keyboard, hardcopy printer, and serial data interface; RF generator/processor with RF generators, background generators, and level controls; RF combiner/noise generators; message simulator with voice, TTY, and Morse telegraphy modules; power supply; and operator manual.
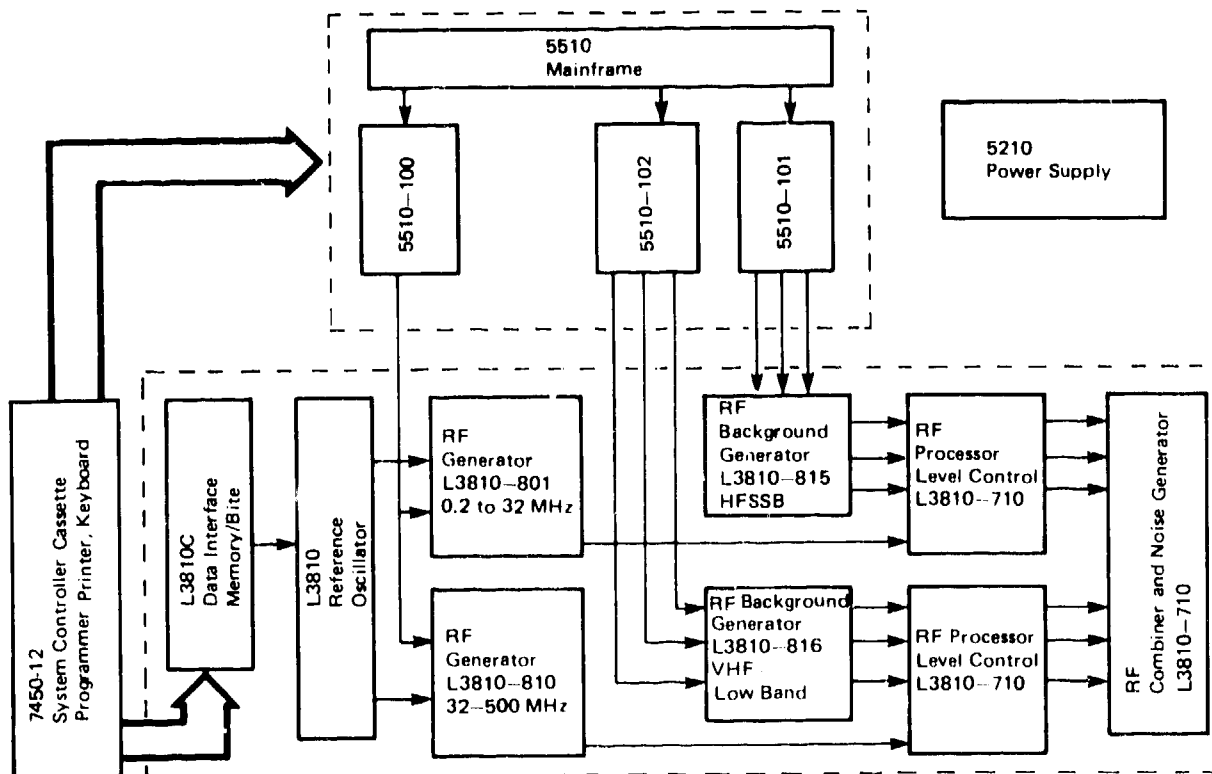

Figure 6. Basic Model 8520 CSS

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Option 8520-01 DF Simulation Module

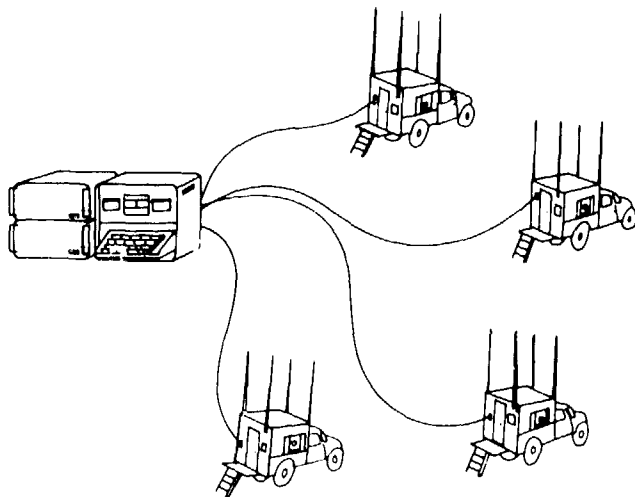This DF modulation option, shown in figure 7, provides the above system with a minimum of four DF outputs.

Figure 7. Model 8520-01 DF Simulation Model

Option 8520-02 High Power for Field Environmental Training

The CSS is basically a closed-loop system to be used for language proficiency training through the use of customer-furnished tapes. However, for a field training environment, (see figure 8) a high power amplifier and antenna system can be added. This option is designed to operate with all other options except Option 8520-01
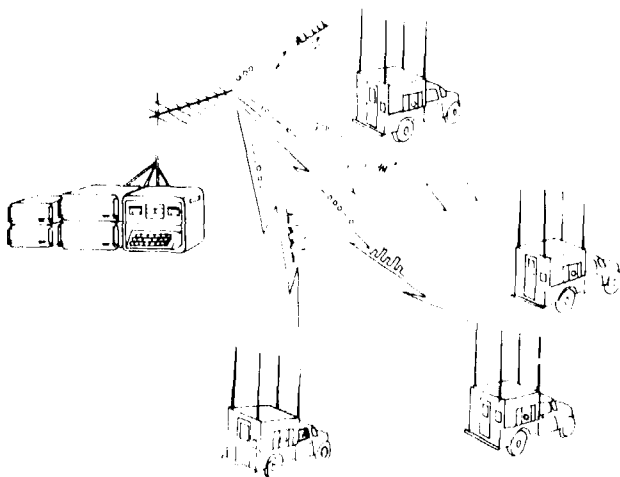

Figure 8. Option 8520 Simulation Module

Option 8520-03 Interference Generator

The interference generator provides the tones, pulses, and noise necessary to replicate those jamming signals presently used against communications networks. This option can be used in a closed-loop environment or with Option 8520-02 in a field environment. Signal selection and signal levels are controllable by a preprogrammed scenario or controlled real-time through the 7450-12A terminal.

V. OPTION 2

Antekna Model 8520 Communications Simulation System was designed to fulfill the requirements of those customers needing a small, cost-effective system with options capable of providing training to most military and municipal exercises.

Systems designed to support a field training exercise are expected to be lightweight, rugged, simple to operate, capable of operating from most power sources, capable of real-time control, cost-effective, and expected to operate for extended periods of time with little or no attention.

For realistic operation, the communications simulators must be capable of operating in almost any language and be versatile enough to be keyed to any training or simulated combat environment. Figure 9 is another version of the 8520 CSS designed for intermediate level training of intelligence, communicators, and collection operators.

VI. PENTAGON 8520

Communications Simulator System (CSS)

RF Environment Simulation. Simulation of "externals" and "internals" of the signal environment.

- Field reprogrammable signal library of 1024 signals

- Frequency Range: 20-500 MHz

- 108 variable background signals

- AM, FM, MCW, BPSK modulation and OOK

- Voice-operated keying

- 120 dB signals level control

Signal Modulation Formats

- Digital Voice

- Analog Voice (cassette tape)

- Automatic Morse

Real-Time Control

- Signal frequency, modulation type, level control, on/off status, interference
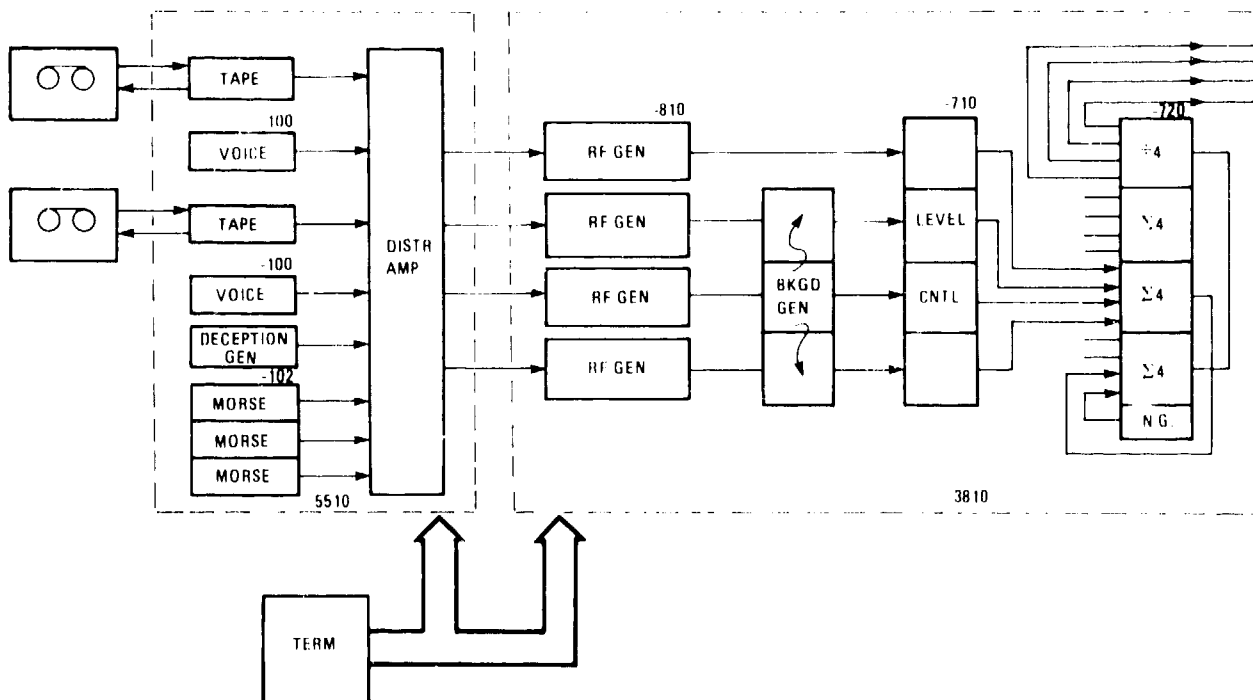
- Scenario execution speed

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Figure 9. Comms Simulator

Figure 10 is the same 8520 CSS with options 1 and 2 added. This version of the 8520 CSS has proven to be the most popular with military users because of its versatility, simplicity of control, and ability to operate from almost any power source.

VII. CEWI 8520

Added capabilities include three DF outputs and a power amplifier output. These can be operated simultaneously with the four closed-loop outputs or can be operated independently. This control can be incorporated into the scenario or can be controlled real-time through the 7450-12A controller.

Packaging

Two packaging concepts are available: the standard 19" cabinet for lab or shelter environments, and a shock-mounted, weatherproof fiberglass traveling case for field environment.

Software

Antekna intermediate-level language facilitates the preparation of scenarios with two-letter mnemonics for network parameters. Typical scenarios of one to seventy-two hours are easily generated and stored in the controller memory. The following is a sample of the typical language form:

FRXXX.XXX,	: FREQUENCY IN MEGAHERTZ (6 DIGITS)
ATR,YY,	: ATTENUATE RF SIGNAL IN DB (2 DIGITS)
ATB,ZZ,	: ATTENUATE BACKGROUND SIGNAL IN DB (2 DIGITS)
BGF,	: BACKGROUND OFF
BGW,	: BACKGROUND WIDE

The Communications Simulation System has proven through extensive field exercises to be very beneficial to the intermediate-level training of all interception, communication, and intelligence personnel.

Reports from activities having used these systems in conjunction with major field training exercises indicate a tremendous improvement in capabilities and morale, and an increase in enlistments. Training a company or squadron of men can be done for less than a one-man TDY training exercise. Readiness or intermediate-level training can be on a daily, weekly, or planned exercise basis. Simulated exercises can be preprogrammed with continuous activity up to 72 hours.
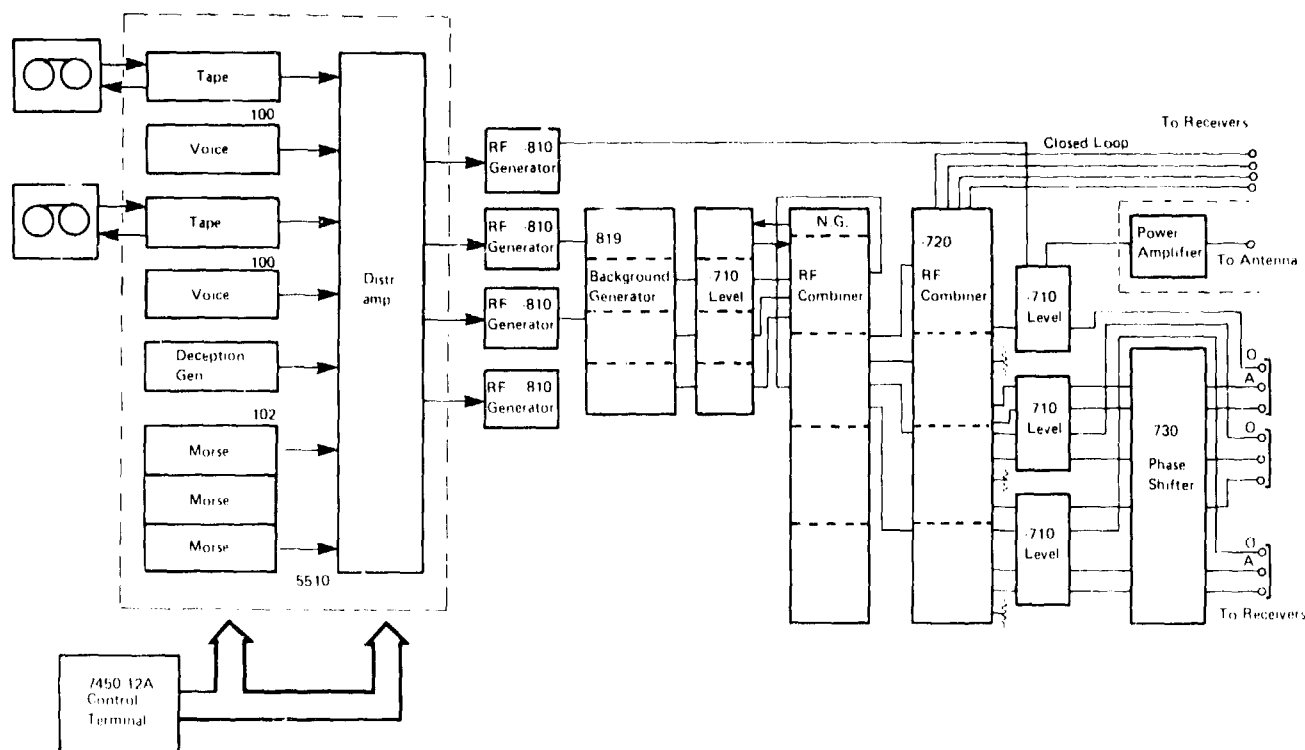
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Figure 10. 3810 Configuration with DF, Closed Loop, and Power Amplifier

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Mr. King received his B.S. degree in Electrical Engineering from Purdue University. His postgraduate studies include work on the Honors Co-op Program at Stanford University and at the University of Santa Clara.

As Manager, Communications Network Simulation Product Line at Antekna, Inc., a Subsidiary of Itek Corporation, Mr. King was responsible for the development of a complement to Antekna's standard radar simulation product line. Included in these responsibilities were the operational and technical requirements for the Communications Network Simulation.

Mr. King is now staff engineer, Systems Department, Applied Technology, Division of Itek Corporation, and is on the staff of the New Threat Warning System (NTWS) program.

B. J. WHITE

Mr. White, a life member of the Association of Old Crows, is presently manager of Antekna's Communication Simulation Product Line.

Prior to joining Antekna, Mr. White was an applications engineer with Watkins Johnson Company, Electronic Warfare System Group.

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